

**publications of the
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MARINE SCIENCE**

Volume 9 / December, 1963

**Published by the
Institute of Marine Science
The University of Texas
Port Aransas, Texas**

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ERRATA FOR
PUBLICATIONS OF THE INSTITUTE OF MARINE SCIENCE, VOL. 8

Page 6, Table 2, Column 4. Read "Total fishes" instead of "Other fishes."

Page 6, Paragraph 2, Line 3. Read "July 17" instead of "July 7."

Page 163, Paragraph 2, Line 10. Read "17.4‰" and "31.2‰" instead of "17.4%" and "31.2%."

Page 98, Line 17. Delete one "and Pachygrapsus."

Page 98, Materials and Methods. Definition of 100% SW omitted. Oceanic SW of [Cl] = 540 mM/L was used as 100% SW.

Page 101, Line 18. mgm. SO₄, instead of MgSO₄.

Page 103, Figs. 2 & 3, 4 & 5. Graphs and legends interchanged, note labels on ordinates.

Page 104, Fig. 7. Legend—delete "from Table 7."

Page 104, Figs. 8 & 9. Legends and graphs interchanged.

Page 105, Figs. 10 & 11. Legends and graphs interchanged.

Page 109, List of conclusions. #'s 1 & 2, "hypo-tonic" instead of "hypo-osmotic."

Page 109, 3rd from bottom. "Blood osmotic concentration" instead of "blood pressure."

Page 117, 26 from bottom. "Table 12" instead of Table 5."

Page 121, 21 from bottom. Substitute "from the Laguna" for "from Austwell."

Page 123, Summary, #1. Substitute "Blood and—" for "Blood of—."

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INSTITUTE OF MARINE SCIENCE, THE UNIVERSITY OF TEXAS
PORT ARANSAS, TEXAS
1962

The Institute of Marine Science with laboratories at Port Aransas, Texas is a research division of The University of Texas related to the Departments of Microbiology, Botany, Chemistry, Geology, Physics, Zoology, Civil Engineering and the Meteorology Division of Aerospace Engineering at the Main University at Austin. An integrated teaching program in graduate marine science is made up of the course offerings from the several departments and from the Institute.

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Helicopter Borne Purse Net for Population Sampling of Shallow Marine Bays¹

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Abstract

A new technique has been developed for sampling animal populations in marine bays. A helicopter-borne net is utilized to trap an area of about 1/40th of an acre (100.4 sq. m.). The net shape is maintained by a light weight, circular, aluminum frame 50 feet in diameter. The net is released in the drop zone by means of an electro-magnetic suspension system, and pursed by boat. Data taken in Corpus Christi Bay (Texas) showed an average biomass of fishes to be 107.7 lbs per acre, ranging from 44.8 to 165.6 lbs per acre (wet weight).

Introduction

The difficulty of estimating aquatic animal populations on a per unit area basis is well known (Hellier, 1962). For the past five years the University of Texas Institute of Marine Science has attempted to estimate stocks in the marine waters of the Texas Coast. Hellier (1959, 1962) contributed the first method in his study with the Drop Net Quadrat for sampling of the shallow areas of Laguna Madre. His device was suspended from pilings and thus had the disadvantage of being limited to shallow water. In addition, Hoese and Jones (1963) in a later study of Redfish Bay, a shallow turtle grass community, found that after the net was dropped the necessity of removing animals from the quadrat by seining destroyed the habitat and was impractical for capture of more agile species.

Next, the stocks of the beach zone were sampled for a year with a special beach seine by a team led by W. N. McFarland (1963).

These methods were not suitable for the deeper bays and a new method was needed where waters were four to fourteen feet deep. After considerable trial and error, a method involving helicopters was finally evolved.

Methods

Description. There is a semi-rigid frame for maintaining the horizontal shape of the net (Fig. 1). This frame forms a circle of 50 foot diameter and is constructed of thin-

¹ This study was supported by an inter-agency contract between the Institute of Marine Science and the Texas Game and Fish Commission (Contract No. 4413-578), Dr. H. T. Odum principal investigator.

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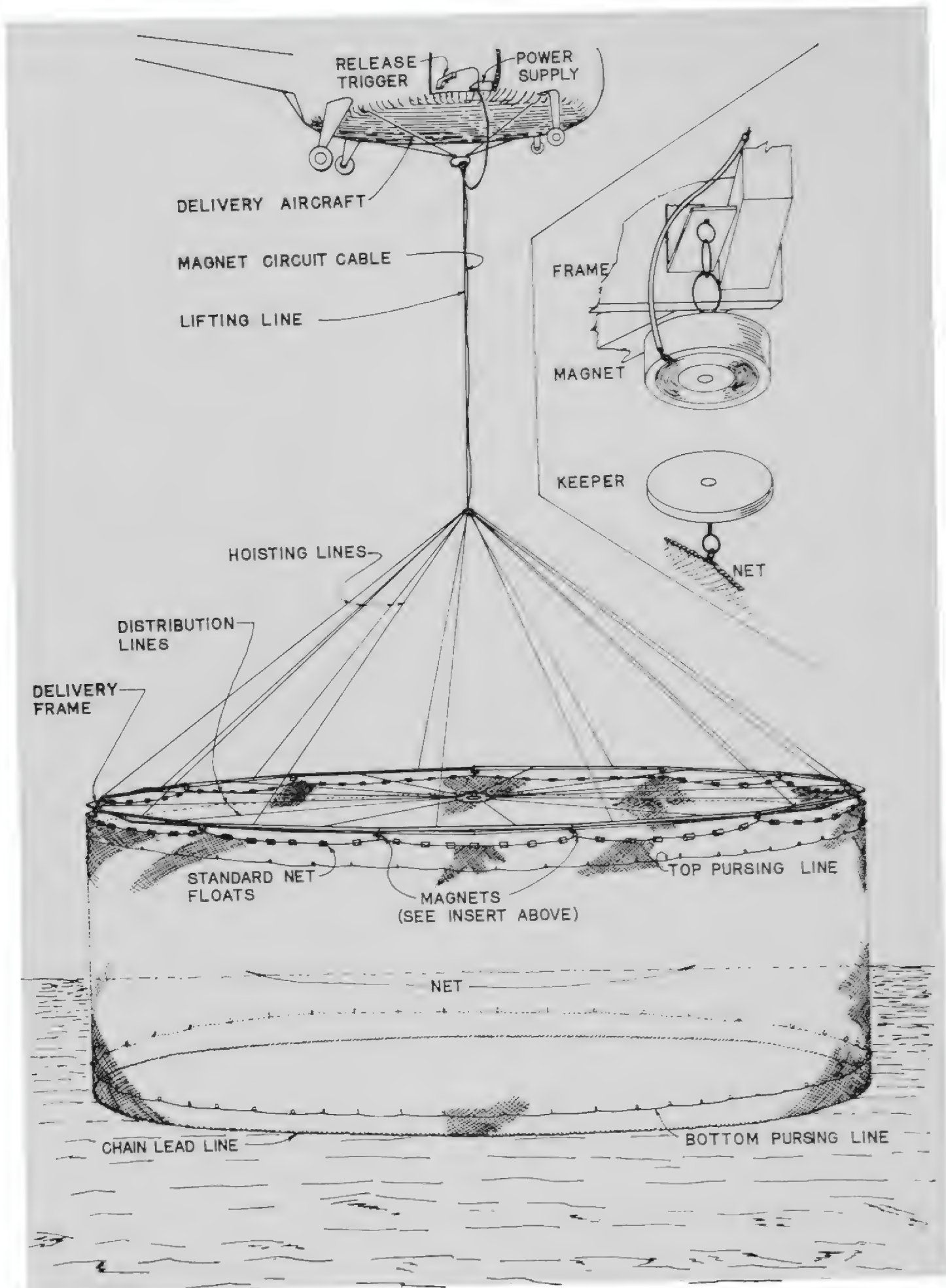


FIG. 1. Complete device, airborne and ready to deliver, with the various parts and lines noted.

walled aluminum tubing braced in the horizontal plane by $3/32$ inch stainless steel cable rigging. A second series of similar cables form a conical hoisting bridle. From this structure is suspended a right circular cylindrical nylon net of $3/4$ inch stretch mesh. The cylinder is 15 feet deep, is weighted with $5/16$ inch galvanized chain, and has a

standard net float line. Upper and lower pursing lines of 1/2 inch nylon are rove through galvanized steel rings sewn into the mesh. The net is suspended from the frame by a series of small electro-magnets. Flexible connections are used to fasten magnets to the frame and magnet keepers to the net float line. The power supply is a 15 volt, high amperage, dry cell unit to serve the primary series circuit of magnets. A 4.5 volt reverse polarity dry cell unit is used to overcome residual magnetism for rapid uniform release of the net. The trigger device, mounted in a pistol grip, has a three position switch. The first position closes the primary circuit through the magnets; the intermediate position is off, and the remaining position is a spring loaded momentary switch to put the depolarizing unit into the circuit. Total dry weight of the device is 540 lbs. The delivery aircraft used thus far is a Navy HRS-3 helicopter (manufactured by Sikorsky Aircraft). It has a lift capacity of 800 lbs with a limited fuel load. The crew for these drops consists of the pilot and one air crewman.

Operating Procedure. The electrical circuit is energized and keepers are positioned to complete the magnetic circuit. The device is then attached to the helicopter cargo sling via a 50 foot length of 1/2 inch manila line and the hoisting bridle. Power supply and trigger are now placed aboard the aircraft. A jettison release on the cargo sling enables the pilot to drop the entire device should an inflight emergency develop. The aircraft rises vertically with the air crewman tending the slack rigging until it becomes taut and the stretched skirt of the net is lifted clear of the ground. At this time the pilot "transitions" from vertical to horizontal flight and is dispatched by radio to the drop area while maintaining a gradual climb to an altitude of 500 feet (Fig. 2). Optimum airspeed for this operation has been about 30 knots. Once in the drop area, forward speed is reduced to zero and the net is permitted to stabilize as the aircraft makes a vertical descent until the chain line is approximately 50 feet above the water. At this time the signal is given to release the net. The trigger is moved from full power position to the momentary depolarizing position and the net is dropped into the water in a uniform circular pattern with the chain line sinking rapidly to the bottom. The still airborne frame is returned to the beach by the helicopter.

For pursing, (Fig. 3), the tending vessel moves into a position upwind of the net and drops anchor. The anchor line is veered until the stern of the vessel is within 20 feet of the float line. A strain is taken on the lower pursing line parallel to the bottom by a hauling line. To keep it parallel, the hauling line is pulled through a ring on a deadman (Tom) positioned on the bay bottom. The bottom of the net is effectively drawn into a tight purse against the deadman. On previous test drops we have found that our pursing operation has been efficient enough to capture several tongue fish, *Symphurus plagiusa* (Linnaeus). The top pursing line is retrieved and the top of the net is easily pursed by hand. The closed bag is hoisted aboard and transported back to the laboratory where the specimens are removed for processing.

Biological Aspects

Calculation of sample size is made on a pounds per acre and g/m² basis with the area of the device equalling about 1/40th of one acre (100.4 sq. m.). Table 1 shows the order of magnitude and species taken for the first series of drops made in Corpus Christi Bay.

This device has the advantage of deep water sampling, unlimited mobility for unbiased sampling, and the complete and rapid isolation of a known sample area from an air-



FIG. 2. Device airborne and enroute to drop area.

borne vantage point. We have found the area to be somewhat variable in that there is a natural tendency for the net to constrict somewhat after release. The geometric shape remains reasonably constant but the 50 foot diameter is reduced to an average of 37 feet. In the drop position (chain line 50 feet above water), the helicopter is at an altitude of approximately 140 feet and the disturbance it may cause over the habitat by noise, downdraft, etc., is negligible. Unless the sun is directly overhead, all shadows are cast

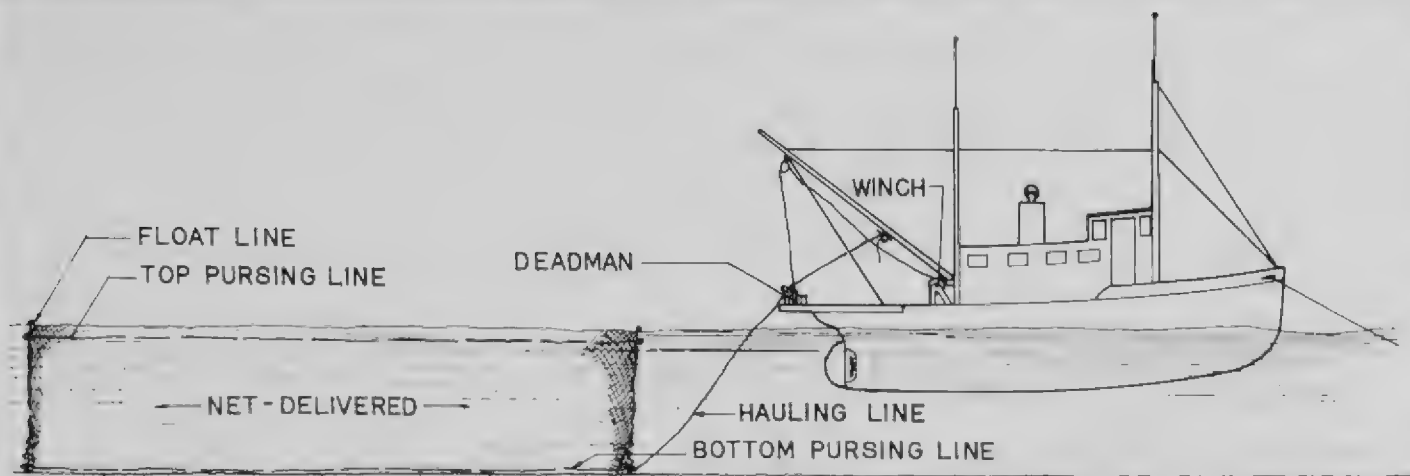


FIG. 3a. Net delivered, hauling line attached to bottom pursing line, and deadman ready to put overboard.

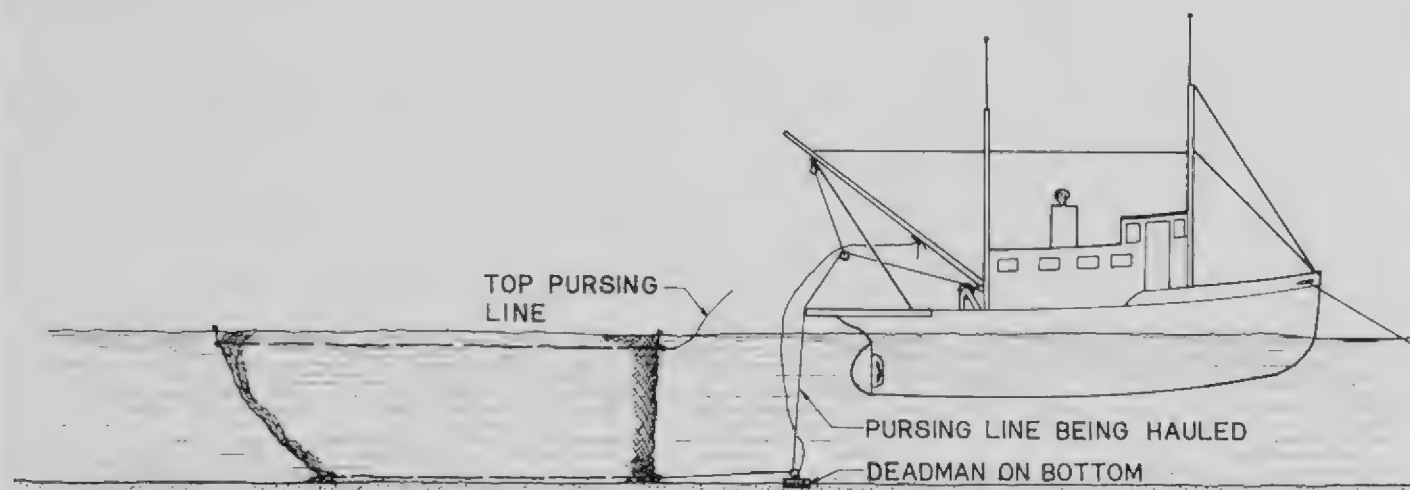


FIG. 3b. Pursing the bottom of the net.

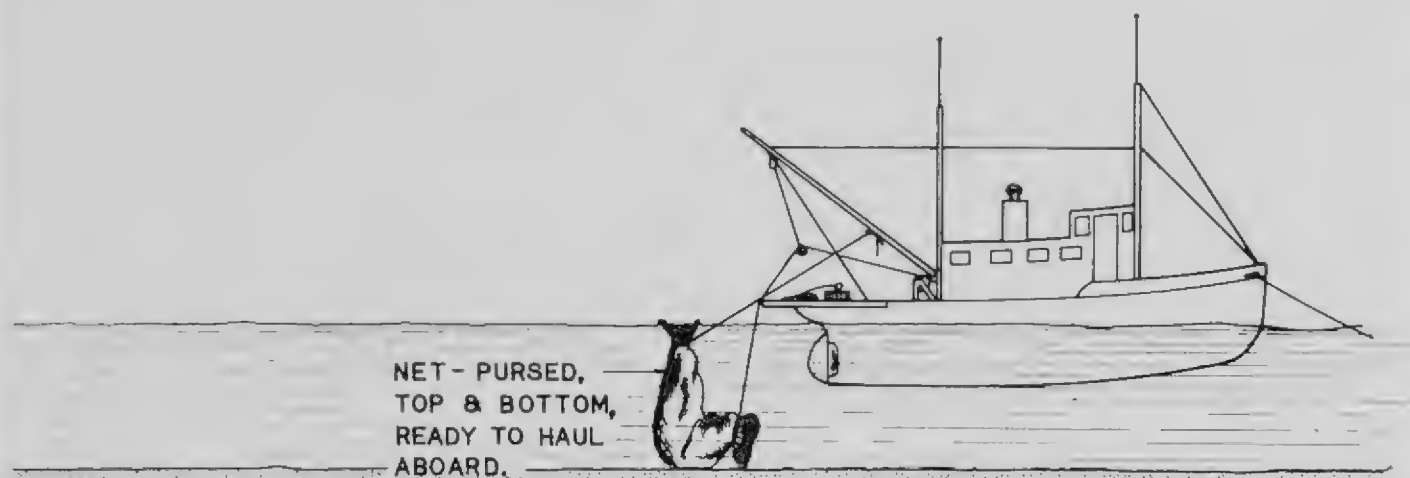


FIG. 3c. Top and bottom of net pursed, deadman returned to the boat and net ready to haul aboard.

well out of the drop zone. Normal wind action and the mirroring effect of the sun on the water surface renders the entire device invisible to subsurface organisms.

The device is now considered operational and is being used to conduct a study of Corpus Christi Bay. With modifications future applications may include: population sampling in the shallow Gulf up to 10 fathoms, and harvesting tightly schooling fishes like the menhaden and mullet. Aircraft observation of other schooling species is shown by Squire (1961). One British organization is known to be considering helicopters to pull fishing trawls but they are not directly concerned with population sampling (Anon. 1962). Completely independent operation by a surface vessel towing a lighter than air delivery vehicle could be developed replacing the more expensive helicopter operation.

TABLE 1

Yield of fishes from the air delivery purse net by preserved weight per unit acre

	g/m ²					
	Sept. 4 ¹	Oct. 10 ¹	Dec. 19	Jan. 4	Feb. 19	Mar. 6
<i>Leiostomus xanthurus</i>	0.66	3.26	2.33	-----	0.65	-----
<i>Micropogon undulatus</i>	-----	0.72	-----	-----	-----	-----
<i>Cynoscion arenarius</i>	-----	6.57	-----	12.65	-----	-----
<i>Cynoscion nebulosus</i>	-----	-----	-----	-----	0.34	-----
<i>Mugil cephalus</i>	-----	-----	11.4	6.07	16.19	7.69
<i>Brevoortia patronus</i>	4.01	-----	-----	-----	-----	-----
<i>Galeichthys felis</i>	0.39	-----	-----	-----	-----	-----
<i>Chloroscombrus chrysurus</i>	-----	0.09	-----	-----	-----	-----
<i>Anchoa hepsetus</i>	-----	-----	-----	-----	-----	0.01
Catch in g	509.0	1067.0	1378.0	1879.0	1725.0	771.8
TOTALS g per m ²	5.07	10.6	13.7	18.7	17.2	7.7
lbs per acre	44.8	94.0	121.6	165.6	152.0	68.0

¹ These drops were made before the magnet suspension system was developed; frame was also dropped into water.

Acknowledgments

This study was made possible through the interest and cooperation of Rear Admiral L. J. Kirn, USN, the past Chief of the Air Advanced Training Command at Corpus Christi, Texas, and his successor Rear Admiral F. A. Brandley, USN. Participating helicopter pilots were LCDR Jim Hamburg, USN; LCDR O. E. Gercken, USN (also our present liaison officer); Lt. W. I. S. Easton, USNR; Lt. J. E. Woolum, USN; and Capt. Robert Bray, USA. During the initial development and subsequent drops, Wayne Fleniken, Emilio Guerra, Reece Brown, Don Wilson, and Ray McKnight served as research assistants. We are also indebted to Herman Moore, Captain of the *M/V Lorene*, and to Dr. B. J. Copeland for his unbiased observations and criticism of the drops.

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Buried Pleistocene River Valleys in Aransas and Baffin Bays, Texas

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Abstract

A sub-bottom echo-sounding survey with a sonoprobe showed the extent of buried Pleistocene valleys in Aransas and Baffin Bays. The form of Baffin Bay follows the buried valley more closely than do the forms of other estuarine bays. This might be explained by the particular set of hydrographic forces operating in Baffin Bay. However, similarly reflecting beds at different depths in different bays suggest that differential subsidence could also explain this observation.

A single core in Aransas Bay combined with the sonoprobe data suggests a depositional history that is similar to the history of San Antonio Bay except for a period of river sedimentation in Aransas Bay. This event might also be explained by differential subsidence or, alternatively, by past changes in the drainage basins emptying into Aransas Bay and its tributaries.

Introduction

The form of the coastline of Texas is a result of present day processes acting upon physiography inherited from the Pleistocene. Perhaps the most notable of the inherited physical features are the river valleys which were eroded during periods of extensive continental glaciation and consequent low stands of sea level. This report is concerned with the relationship between two of these river valleys and the bays (Aransas Bay and Baffin Bay) which now occupy them (Fig. 1).

Procedure

The channels of the Pleistocene rivers that have been located in a few of the Texas bays were discovered chiefly by coring (e.g., Parker, 1959; Fagg, 1957). In the present study all subsurface data were collected with a sonoprobe on loan to the Institute of Marine Science from the Texas Game and Fish Commission. This instrument gives a continuous recording of echo-sounding reflections from subsurface horizons of contrasting density. For further description of this instrument see McClure, Nelson, and Huckabay (1958). The sonoprobe's chief advantage is that with it the time and effort involved in delineating a particular subsurface feature is about two orders of magnitude less than would be required by coring. The sonoprobe has two disadvantages: first, it gives no information on the composition of the sediment (this is not quite true; lithologically different beds produce different types of reflections; but, as yet, there are insufficient data to allow interpretation of sedimentary parameters from echograms); second, the recording portion of the instrument must be calibrated to a single assumed speed of the emitted sound impulses. This assumed speed is the speed of sound in water—approximately 4800 feet per second. Insofar as the speed of sound increases when the impulses enter the sediment the sonoprobe results are inaccurate. Although no measurements of acoustic properties of the sediment involved were made, such measurements on

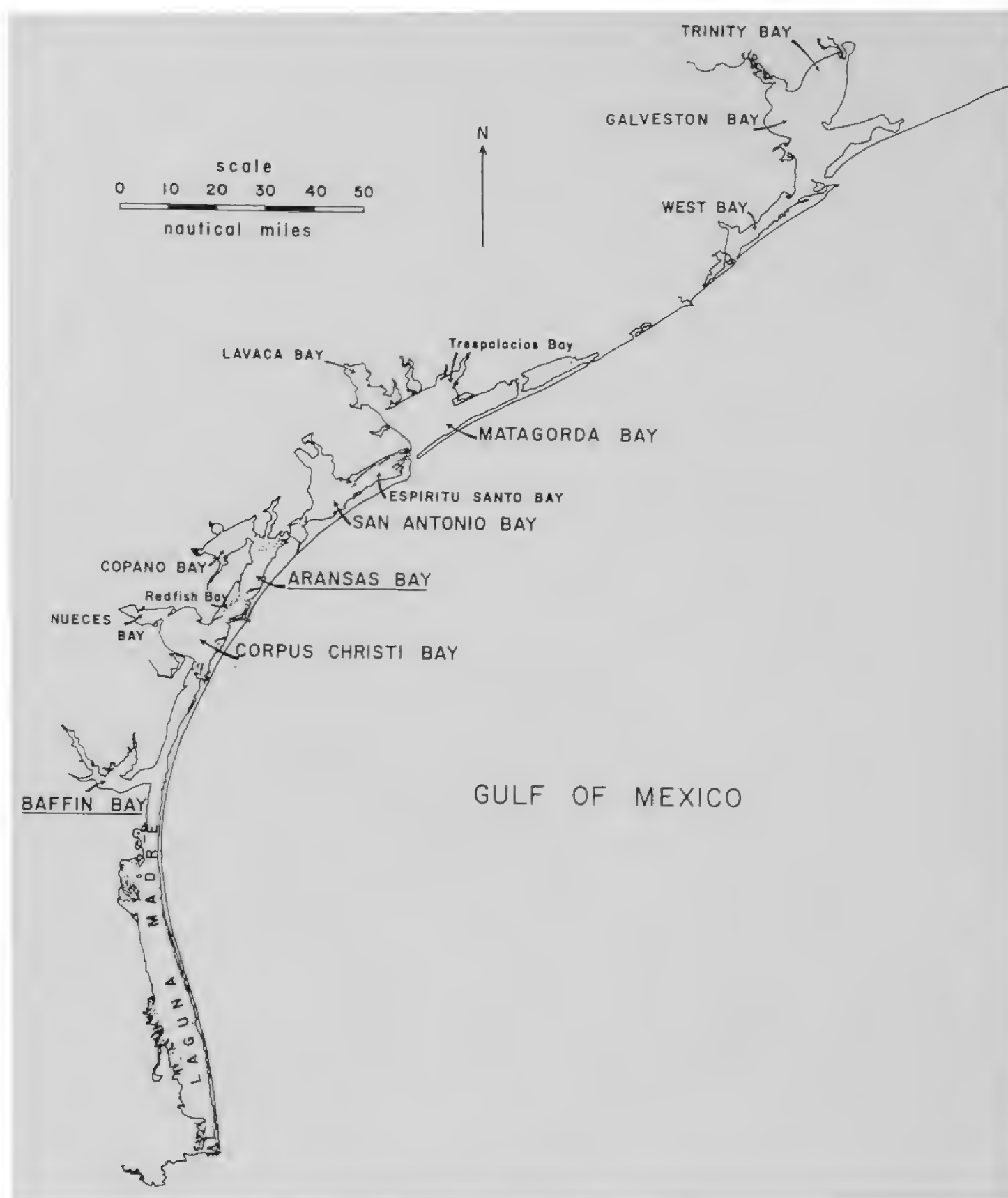


FIG. 1. Index map of the Texas coast.

similar, Recent, unconsolidated sediments indicate that the speed of sound in them generally ranges from 4900 to 6000 feet per second (Shumway, 1958; Moore and Shumway, 1959). As a first approximation a correction to 5040 feet per second (1.536 km/sec) was made in the present study.

Results

Figs. 2 and 3 show the locations of the sonoprobe traverses in Baffin Bay and Aransas Bay respectively. Figs. 4, 5, and 9 are reproductions of the sonoprobe recordings along some of these traverses with the depths corrected as noted above.

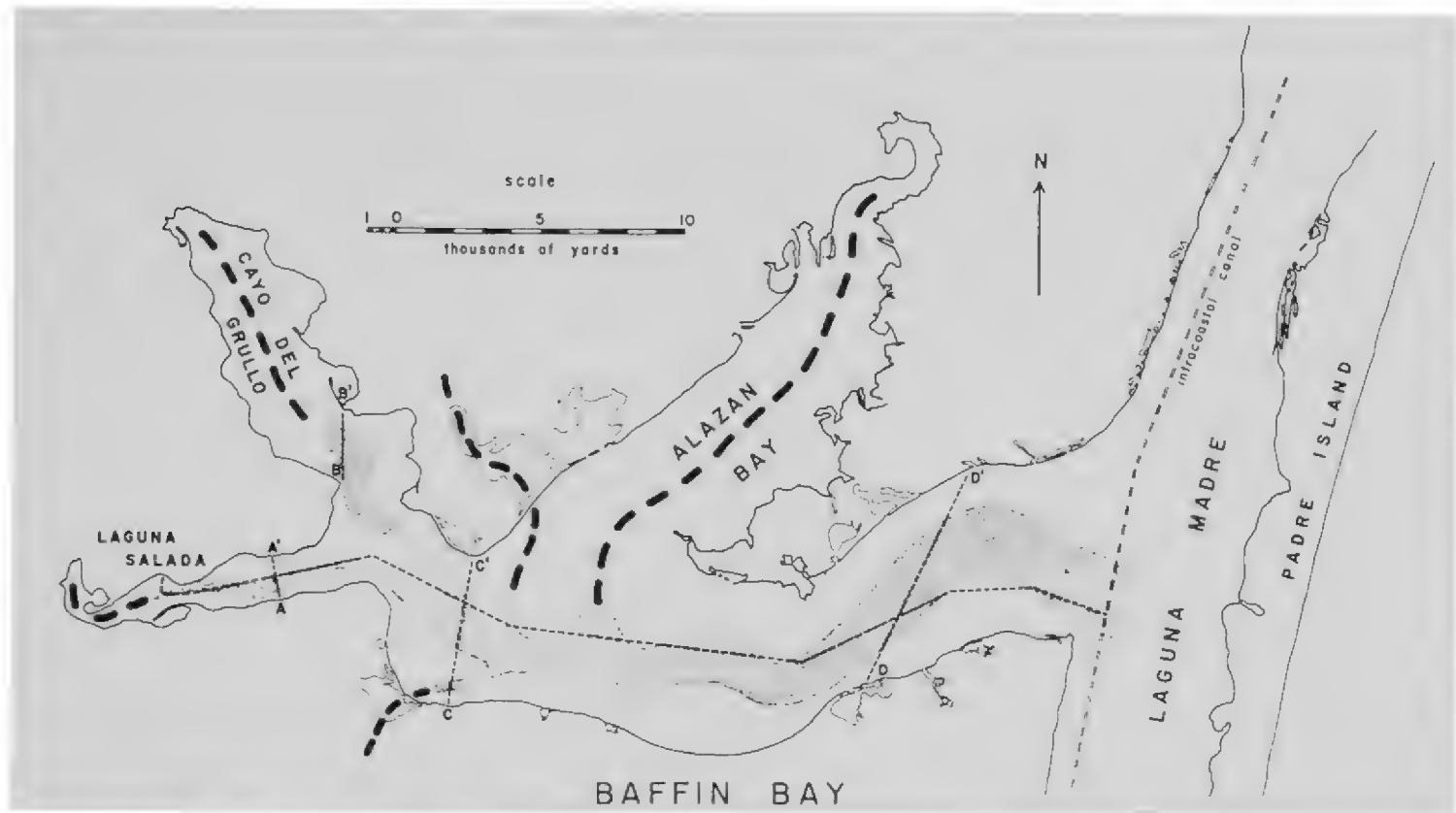


FIG. 2. Baffin Bay, Texas. Light dashed lines show locations of sonoprobe traverses; shaded area shows extent of buried Pleistocene valleys; heavy dashed lines show probable axes of tributary streams.

Discussion

General. Texas bays are basically of two types. The first type is characteristically elongated parallel to the coast, and the form bears no apparent relationship to present-day river systems. Bays of this type are referred to herein as lagoons. Major lagoons of the Texas coast include Laguna Madre, Redfish Bay, Espiritu Santo Bay, lower Matagorda Bay, and West Bay. Some of the forms of the second type of bay reflect dendritic river patterns, and major streams usually enter the bay heads. The long axes of these bays are generally perpendicular to the coast, although some are oblique or parallel to it. Major bays of this type include Nueces—Corpus Christi Bays, San Antonio Bay, Lavaca—Tres Palacios—central Matagorda Bays, and Trinity—Galveston Bays. Bays of this type are referred to herein as estuarine bays.

Lagoons are considered to have originated simply as water impounded behind Recent barrier islands (Price, 1947; LeBlanc and Hodgson, 1959). Estuarine bays originated as river valleys deeply eroded during periods of continental glaciation and consequent lowered sea level and were subsequently flooded as the glaciers melted and sea level rose (Price, 1933, 1954). Pleistocene river valleys also may be buried beneath parts of some lagoons (Fisk, 1959), but the lagoons do not owe their existence to these valleys as do the estuarine bays.

Baffin Bay. Baffin Bay (including Alazan Bay, Cayo del Grullo, and Laguna Salada) has all the characteristics of an estuarine bay except that the associated streams are small and often dry. The form of Baffin Bay is actually closer to a river valley system than is the form of any of the other large estuarine bays; and the sonoprobe results show that this form parallels closely the underlying, buried valleys (Fig. 2). The question arises, why has the form of this bay remained so close to that of the buried river valleys in which it originated? Three hypotheses are considered.

Hypothesis 1. Baffin Bay is a relatively shallow basin which was invaded by the sea

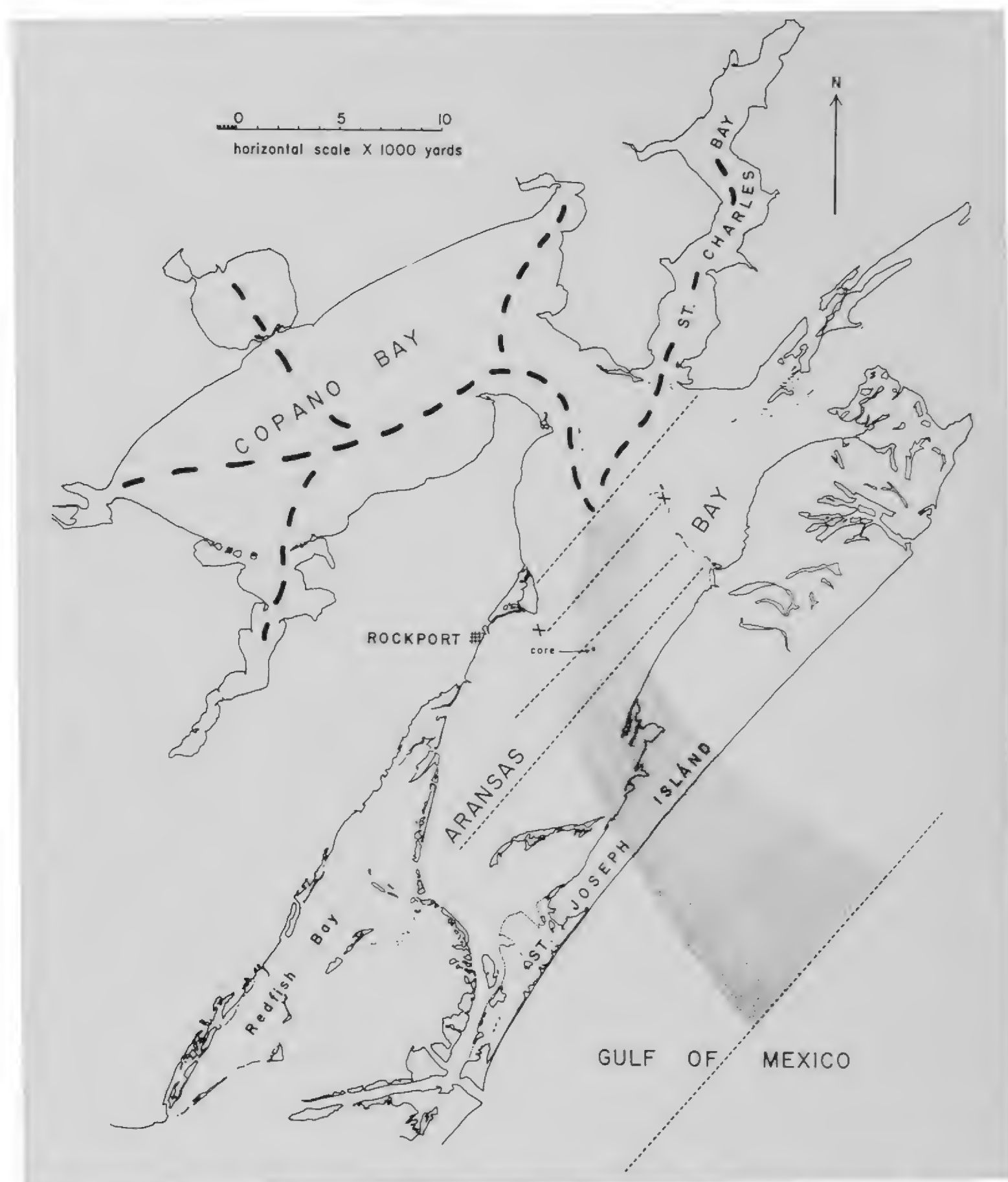


FIG. 3. Aransas Bay, Texas. Light dashed lines show locations of sonoprobe traverses; shaded area shows extent of buried Pleistocene valley; heavy dashed lines show probable axes of tributary streams.

later than were other estuarine bays. Thus waves and tidal currents have not had time to modify the shape of the basin. The sonoprobe records show that the valleys in Laguna Salada and Cayo del Grullo are approximately 55 feet deep. (All depths are given in feet below sea level.) Therefore in lower Baffin Bay the valley bottom probably lies 60 to 80 feet below sea level. In San Antonio and Matagorda Bays valley depths of 83 feet and less than 80 feet, respectively, have been determined by coring (Shepard and Moore,

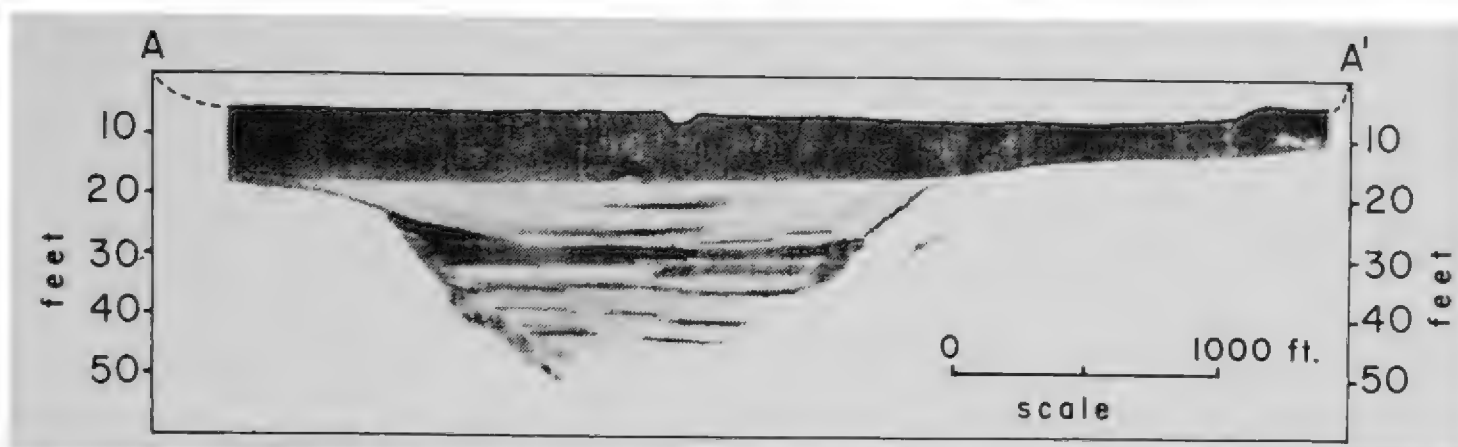


FIG. 4. Reproduction of echogram from Baffin Bay; see Figure 2 for location of the section.

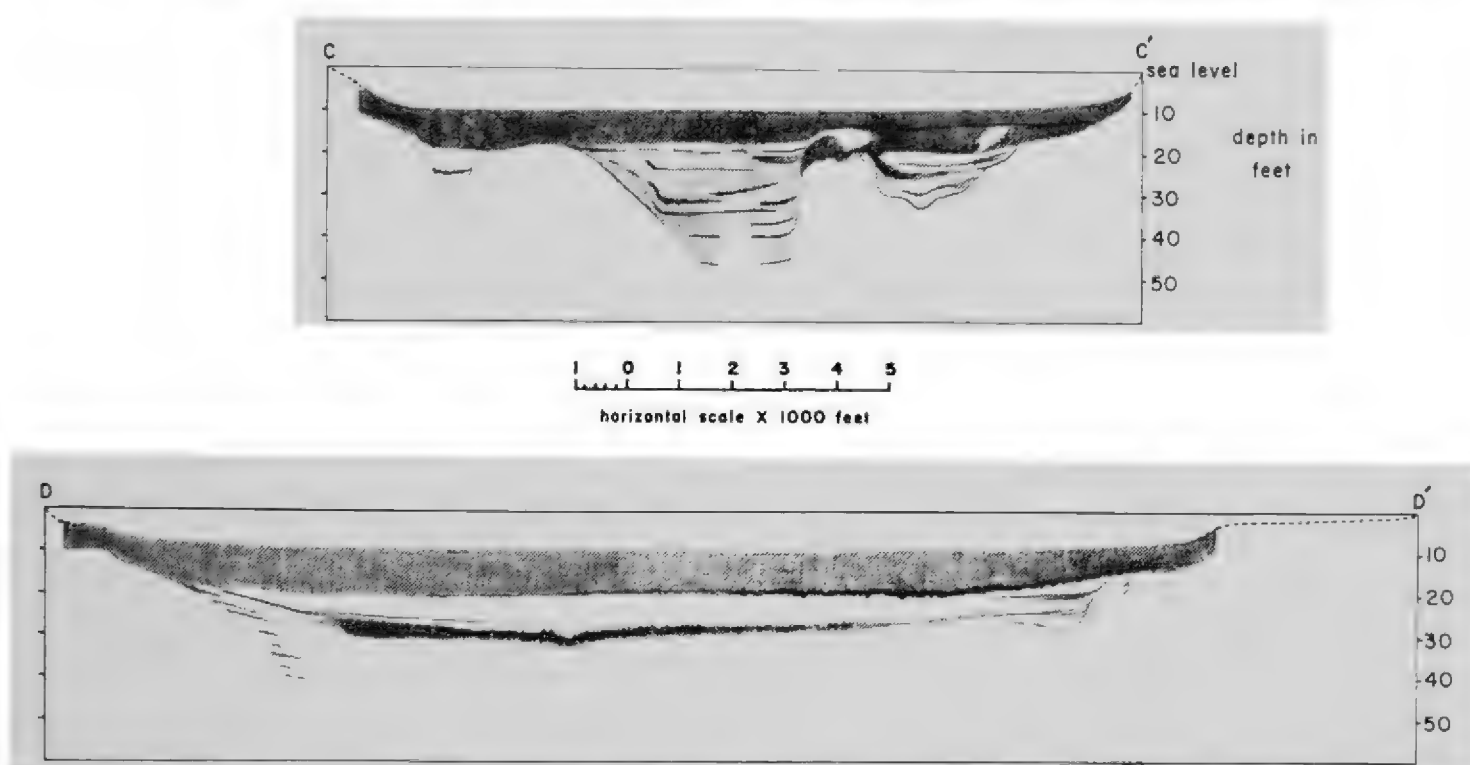


FIG. 5. Reproduction of echograms from Baffin Bay; see Figure 2 for location of the sections.

1955; Fagg, 1957). This evidence suggests that the differences in valley depths are insufficient to account for differences in bay forms.

Hypothesis 2. The interior forces which modify a bay's form are less effective in Baffin Bay than in other estuarine bays. Price (1947) has pointed out that the forms of tidal basins along the Texas coast appear to be in dynamic equilibrium with normal or interior forces such as tidal currents, waves, wind driven currents, gravitational settling of sediments, chemical precipitation, growth of bottom dwelling organisms, and the effect of rainfall and wind on the immediate basin margins which extend above water level.

There is little apparent difference between celestial tides in Baffin Bay and those measured at Corpus Christi and Rockport (Breuer, 1957; Collier and Hedgpeth, 1950). Tide data are scarce, however, and measurements of tidal currents, or indeed of any bottom currents, are nil.

Sedimentation in hypersaline Baffin Bay certainly differs from sedimentation in the generally brackish-water estuarine bays to the north. However, Breuer (1957) cites evidence (e.g., oyster bearing middens at Indian camp sites) suggesting that until very recently conditions in Baffin Bay were quite similar to those in presently brackish estuarine bays. In fact, a pass to the Gulf may have been open until very recently in Baffin Bay's history (Price in Breuer 1957, p. 138-139).

Wave action is, perhaps, the most important interior force affecting bay shorelines. The writer is indebted to Dr. W. Armstrong Price for pointing out several aspects of wave action discussed in this section. It is well known that wave fronts are perpendicular to wind direction. It is also well known to coastal residents that the strongest winds commonly blow from either the southeast or the northeast. The predominance of the southeast wind is apparent from weather bureau statistics (Fig. 6). The effectiveness of these winds is apparent in the straightness of several northeast trending shorelines (Figs. 1, 2, and 3). Strong northeast winds are not brought out in the wind rose probably because they are of relatively short duration usually accompanying cold fronts in the winter months. The air associated with these winds is cold, heavy, and usually wet, and the winds are often of gale force. Several northeast facing bay shores attest to the effectiveness of waves generated by these winds to straighten shorelines (Fig. 1). Fig. 7 shows that the fetches of these two dominant winds are generally less in Baffin Bay than in other Texas bays. Insofar as bays are enlarged as well as their shorelines straightened by this wave action the different orientation of Baffin Bay contributes to its relative lack of enlargement.

In addition, the shores of Baffin Bay may be relatively difficult to erode. For example, the shore sediments have been cemented into beach rock at several places in Baffin Bay (personal communications from Dr. W. Armstrong Price of Corpus Christi and Mr. Donald W. Dalrymple of Rice University). Concerning the north shore of lower Baffin Bay Rusnak (1960, p. 167) states "... the relative wave strength is reduced by shoal water above a shallow platform consisting of dense, brown Pleistocene beach rock fronting the shoreline." A similar ledge of this beach rock capped by serpulid reefs has probably formed an effective hydrographic barrier across most of the mouth of Baffin Bay (personal communications from Dr. W. Armstrong Price of Corpus Christi and Mr. Donald W. Dalrymple of Rice University). Numerous rocky shoals within Baffin Bay (e.g., across the mouth of Alazan Bay) probably also serve to break up the fetch of winds and thus to diminish wave effectiveness. However, these rocky shoals might have had no

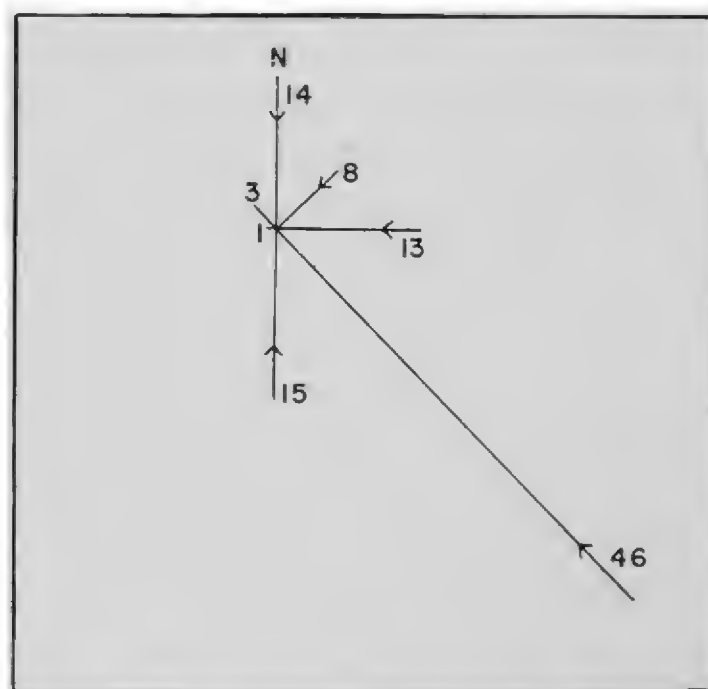


FIG. 6. "Wind strength . . . at Corpus Christi. Data from United States Weather Bureau. Relative strength of wind (in percentage of all winds) derived from products of squares of average hourly velocities (1923-30 period) multiplied by average duration for each wind in percentage of time (1923-31) period," as developed by Price. (Price, 1933, Fig. 9, p. 933.)

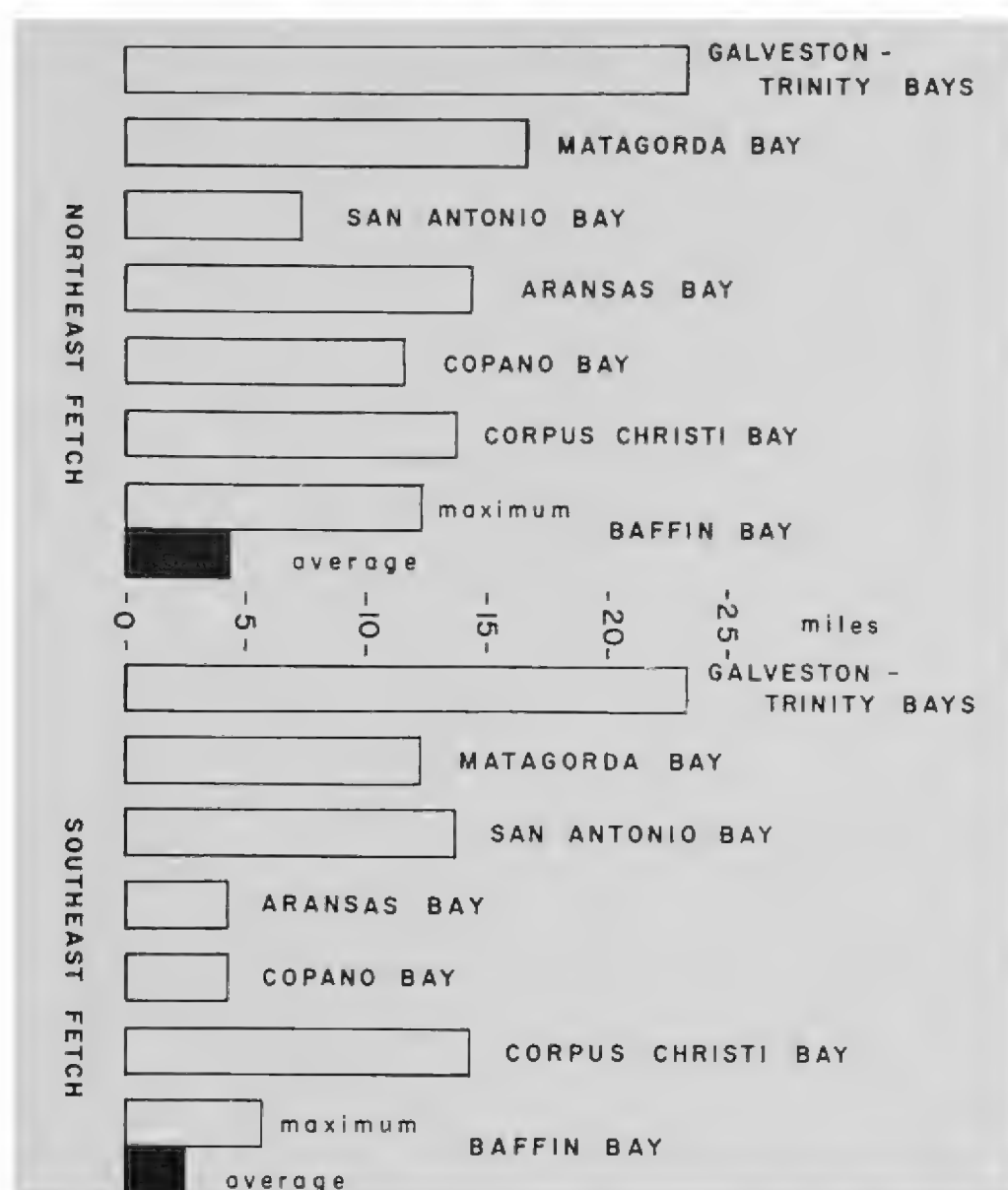


FIG. 7. Maximum fetch lengths for northeast and southeast winds in major Texas bays. The maximum fetch extends over a broad area in most bays and is thus nearly equal to the average; however in Baffin Bay maximum fetch lengths are located in long narrow arms of the bay, and average fetch lengths are considerably less.

more effect than oyster reefs in the brackish estuarine bays to the north. For example, the southwest shore of Copano Bay shows considerable straightening normal to the northeast winds. However, three oyster reefs segment the bay by cutting directly across the fetch of this wind.

In the absence of more detailed hydrographic information this hypothesis probably should be neither accepted nor rejected at this time.

Hypothesis 3. Baffin Bay has remained essentially stable whereas other major estuarine bays have subsided to some extent since they were initially flooded. Subsidence of the coast of the northwest Gulf of Mexico has been noted by several workers (e.g., Russell and Howe, 1935; Price, 1947; Marmer, 1952). Concerning the Mississippi delta region since the last glacial maximum Fisk and McFarlan (1954, p. 279) state "The continental margin has subsided during deposition, forming a trough-like depression which is localized to the depositional area. This trough has been downwarped more than 350 feet near the present shoreline and more than 500 feet offshore on the continental shelf." This subsidence accounts for roughly 50% of the total section to the base of the Mississippi trench.

The sonoprobe records for Baffin Bay commonly show one or two strongly reflecting horizons at 24 to 32 feet (Figs. 4 and 5). Similar strongly reflecting beds in Aransas

Bay occur at depths of 47 and 54 feet, and in Corpus Christi Bay at depths of 60 to 61 feet. The similarity of their reflections suggests that these beds may represent a common event. If subsidence also accounts for about 50% of the sections in Aransas and Corpus Christi Bays but was essentially nil in Baffin Bay, then all of these beds would have been deposited at about the same depth (24–32 feet). This same subsidence could then account for more widespread flooding and expansion of estuarine bays whose forms do not follow buried river channels so closely as does the form of Baffin Bay (Fig. 8).

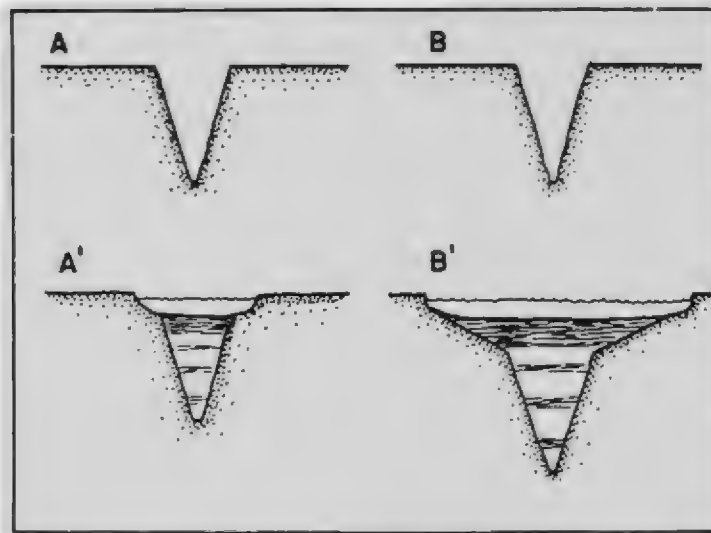


FIG. 8. Hypothetical development of estuarine bays. A-A': Pleistocene valley is filled with sediment as sea level rises; wave erosion expands bay slightly beyond original valley walls; no subsidence. B-B': same history as in the A-A' sequence except subsidence has depressed valley walls resulting in a wider bay.

Aransas Bay. Although Aransas Bay looks like a lagoon several small rivers feed it through Copano Bay and an estuarine bay (St. Charles Bay) enters it at the north end. Thus one might suspect that Aransas Bay actually had a compound origin, and a Pleistocene valley lies buried beneath it. The sonoprobe results show that this is, indeed, the case. Fig. 3 shows the areal extent of this buried valley and Fig. 9 shows a cross section of it.

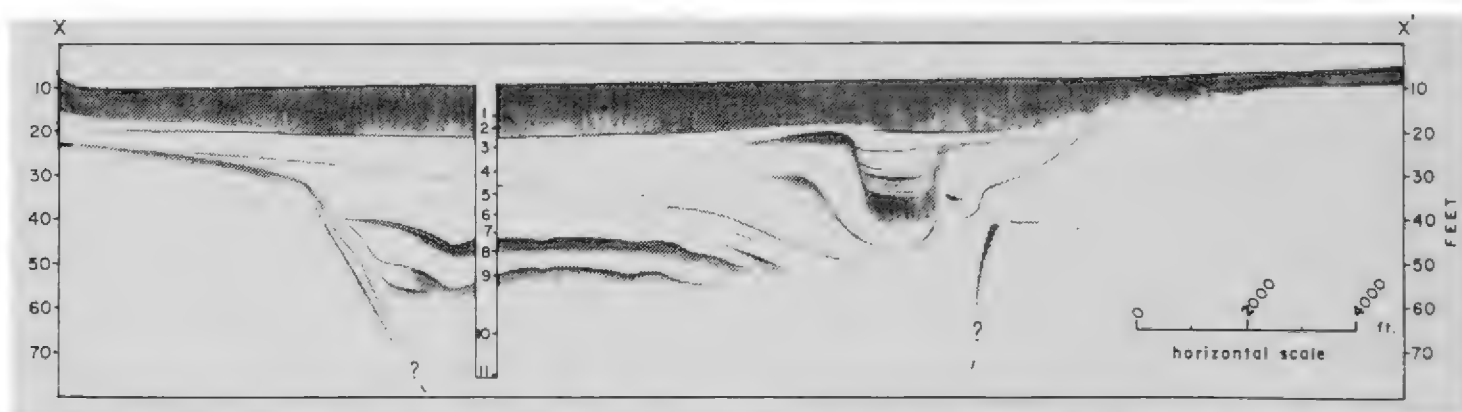


FIG. 9. Reproduction of echogram from Aransas Bay; see Figure 3 for location of section. See text for descriptions of the samples numbered in the core.

Shepard and Moore (1955, p. 1561–1562) describe a core from Aransas Bay which when correlated with the cross section shown in Fig. 9 suggests some of the detailed depositional history of this bay. Shepard's and Moore's descriptions and interpretations of the samples numbered in Fig. 9 are summarized below.

1. "... the high percentage of Foraminifera in the coarse fraction indicates the 'bay

- no special influence' environment which is found also in the surface samples" (op. cit., p. 1561).
2. Foraminifera and shells become scarce; glauconite high, no echinoids; Foraminifera and macro-organisms suggest bay environment but unlike present bays.
 3. Sand down to 11.6%, silt up to 50.4%, Gulf Foraminifera, bay macro-organisms, both scarce; an enigma.
 4. Foraminifera and shells abundant; "The presence of aggregates suggests the possibility that the sediment is a land deposit" (op. cit., p. 1562).
 5. Same as sample 4.
 6. Same as samples 4 and 5 except slightly more sand.
 7. Same as samples 4, 5, and 6 except slightly more aggregates.
 8. Shells abundant, coarse fraction up to 69%, Foraminifera common; inlet environment.
 9. Coarse fraction up to 85.6%, Foraminifera scarce, grains rounded slightly less than in dune sand; barrier island flat.
 10. Sand down to 37%, abundant shells and Foraminifera of open Gulf and lower bay type, glauconite and echinoids suggest a connection with the Gulf.
 11. Mixed Gulf and lower bay fauna, coarse fraction 36%, glauconite and echinoids scarce, relatively protected bay.

In Fig. 10 the depositional history interpreted from these data is depicted and can be compared with the history of San Antonio Bay (Fig. 11) as interpreted by Parker (1959). River influenced estuarine sediments were encountered immediately above the Pleistocene in the ancient San Antonio river channel. These are overlain by sediments presumably deposited in a bay enclosed by a pre-existing high which acted as a barrier island and was located beneath the present barrier island (Parker, 1959). The base of the core in Aransas Bay appears to have penetrated to an equivalent horizon of enclosed bay sediments. Thus a pre-existing barrier ridge presumably also underlies St. Joseph Island. As sea level rose above this ridge open bay or sound conditions existed in both bays. These conditions prevailed in San Antonio Bay until the Recent barrier island grew and slowly created the enclosed bay and river influenced environments that exist there today (Parker, 1959).

However, in Aransas Bay the open bay deposits are overlain by two strongly reflecting horizons which Shepard and Moore (1955) interpret as barrier flat and inlet deposits respectively. As such, these beds suggest a very near-by shoreline. The position of the

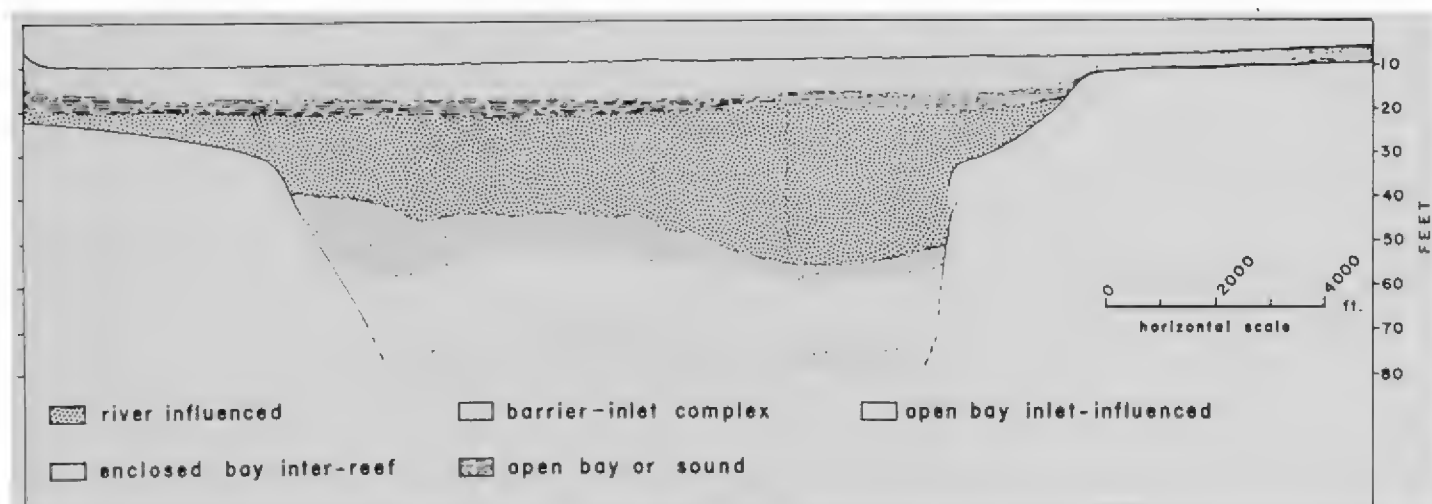


FIG. 10. Interpretation of depositional history of Aransas Bay.

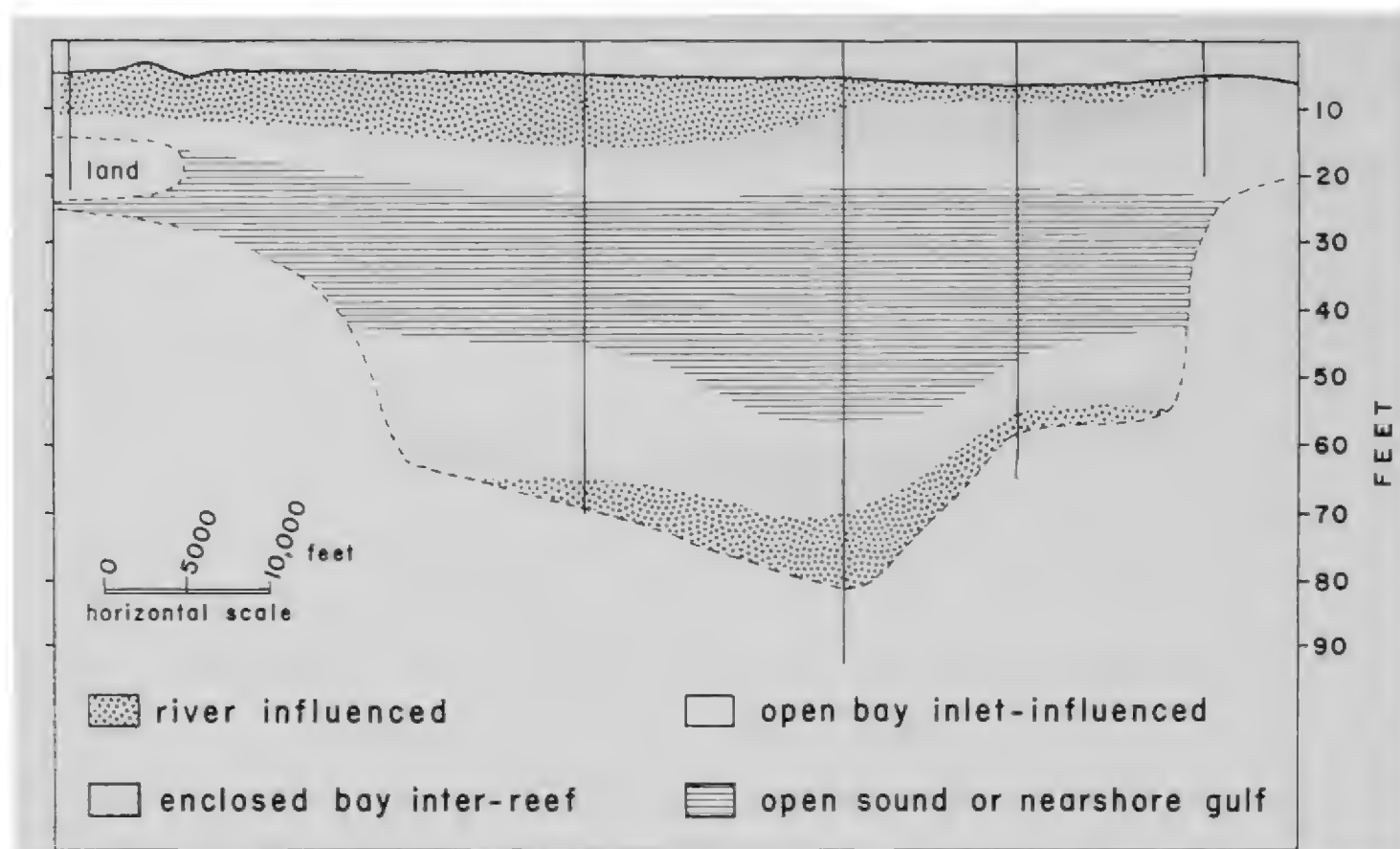


FIG. 11. "Generalized interpretation of depositional history of Mesquite Bay and lower San Antonio Bay, based on macro-faunal evidence." Parker (1959, p. 2155, Fig. 31b). Vertical lines represent cores.

superjacent silty section relative to the river channel shown in the sonoprobe cross section (Fig. 9) clearly indicates that the silt represents flood plain deposits. Apparently the sea regressed relative to Aransas Bay at this time. Above the flood plain silts open bay deposits succeeded by the closed bay deposits which form the present bay bottom suggest flooding and subsequent enclosement of the bay by a growing barrier island just as occurred in San Antonio Bay. If these interpretations are correct, the enigmatic sample (number 3) would represent a reworked flood plain deposit with Gulf and bay organisms mixed in by the transgressing sea.

The question, what caused the sea to regress briefly from Aransas Bay while San Antonio Bay remained open to the Gulf, invites speculation. If, as previously suggested, differential subsidence is indeed an effective agent, the different histories of the two bays could be explained by assuming that San Antonio Bay subsided below sea level at the time that Aransas Bay was receiving fluvial sediments. Alternatively, a period of increased river discharge and consequent sedimentation in Aransas Bay might produce the same effect. Although there are insufficient geomorphic data to evaluate this hypothesis well, two facts suggesting its plausibility should be pointed out. First, the San Antonio River runs perilously close to the northern limit of the area which drains into Copano and Aransas Bays (Fig. 12). Second, St. Charles Bay is a fairly large, apparently estuarine bay with almost no drainage basin. The size of this bay may be due to the fact that it occupies part of a Pleistocene lake or lagoon which lay immediately behind the Live Oak bar or to erosion of a Pleistocene valley by a much larger river than now flows into the bay. Although there is no apparent abandoned interconnecting valley, the San Antonio River is, at present, prevented from draining into St. Charles Bay only by a very low drainage divide. Finally it should be mentioned that these two hypotheses are not mutually exclusive; that is, differential subsidence could have played a major or minor role in addition to fluctuation in river derived sediment.

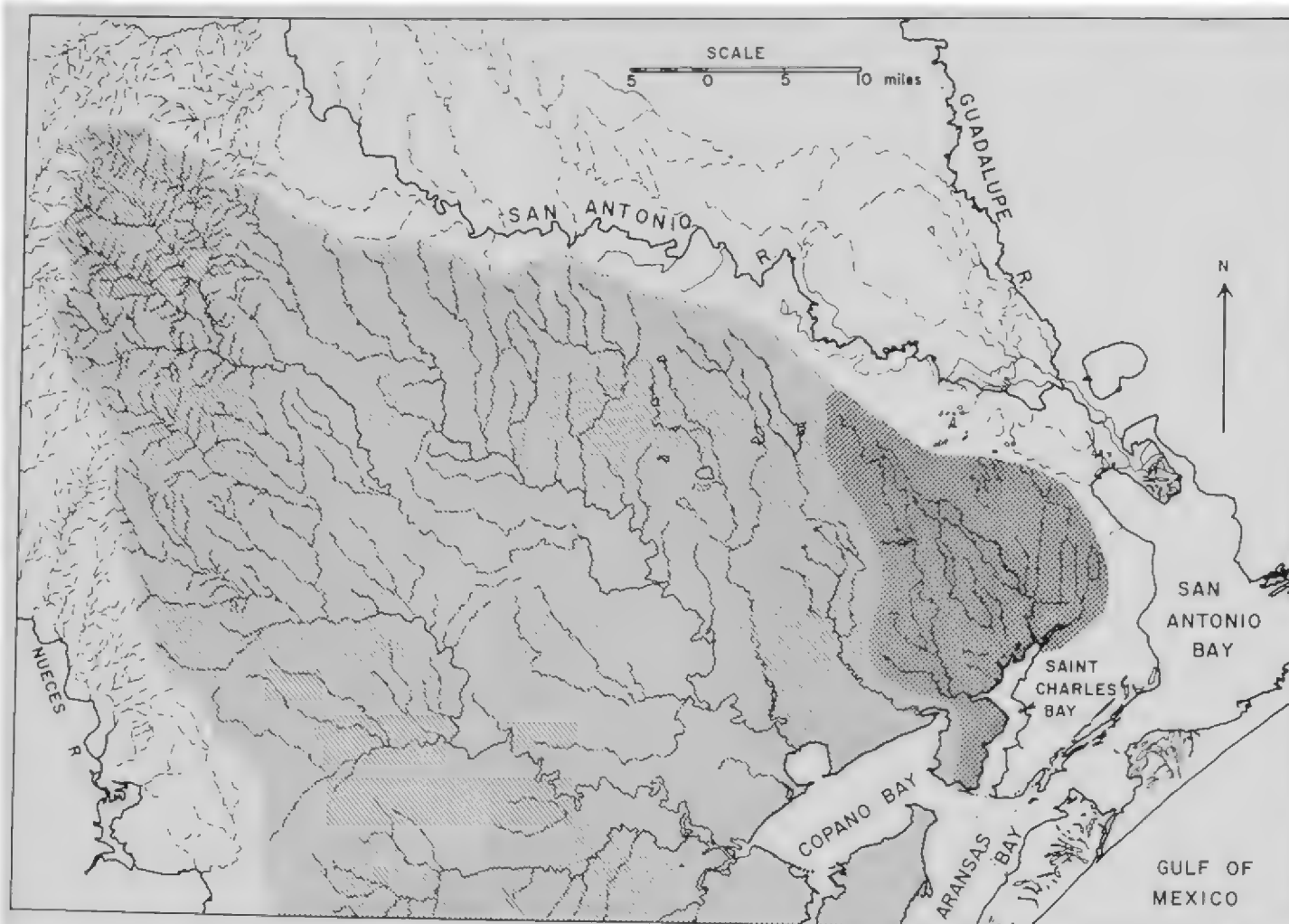


FIG. 12. Drainage basin of Copano, Aransas, and St. Charles Bays. Total drainage area lined; St. Charles Bay drainage area cross-hatched.

Conclusions

The amount of information obtained from a relatively small survey with a sub-bottom echo-sounder, the sonoprobe, shows that this instrument is a most efficient tool for studying the third dimension (depth) and thus the fourth dimension (time) of sedimentary units. This is especially true when sonoprobe results are combined with a small quantity of core data.

Although the observations made in this study have several possible explanations a single process, differential subsidence, may account for similar reflecting horizons occurring at different levels in various bays, different amounts of widening of estuarine bays and different details in the depositional histories of the bays.

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A Characteristic Diurnal Metabolic Pattern in Balanced Microcosms¹

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Abstract

Data are presented on the diurnal pattern of metabolic rates of nine kinds of balanced aquatic microcosms including an oyster reef pond, two coral heads, balanced freshwater aquaria, a blue-green algal mat system, a brine microcosm, a microcosm at 51 degrees centigrade, a temporary pond system, and a green hydra. Net photosynthesis was maximal in the first half of the light period and nighttime respiration was maximal in the first half of the dark period. Similar patterns were noted in nature.

Introduction

The small size laboratory ecosystem is rapidly becoming a fundamental tool in the development of comparative ecology. These artificial ecosystems have been termed microcosms (Odum and Hoskin, 1957), aquarium microcosms (Whittaker, 1961), microecosystems (Beyers, 1962a), experimental ecosystems (Beyers, 1962b), carboy microcosms (McConnell, 1962), or laboratory-scale models (Pipes, 1962). However, regardless of the name, such small systems can be used to compare ecosystems as to metabolic patterns, species composition, successional stages, and other theoretical concerns without the difficulties of replication, size, and ease of application of experimental techniques presented by natural ecosystems.

For a number of years, Dr. Howard T. Odum, several co-workers, and the author have been using the microcosm approach for basic ecological studies carried on at the Institute of Marine Science. In one series of studies (Beyers, 1962a), the author noted that the carbon dioxide rate of change curves from twelve freshwater benthic microcosms showed a fairly regular pattern. The nighttime respiration was at a maximum in the early evening after the lights were extinguished. The respiratory rate then dropped until the lights came on again the next morning. The net photosynthesis showed a similar pattern with production at a maximum immediately after the lights were turned on and with decreasing photosynthesis during the rest of the day. Fig. 1 shows an average of 100 carbon dioxide diurnal rate of change curves in the benthic systems and demonstrates a characteristic shape. To investigate the generality of the pattern, metabolic measurements were made on eight different kinds of microcosms.

Materials and Methods

The diurnal course of metabolism in all the artificial ecosystems was followed using the

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diurnal rate of change concept of Odum, 1956 and Odum and Hoskin, 1958. The advantage of this free water method, as opposed to any of the more conventional bottle methods, such as light and dark bottles or the carbon fourteen method, is that the data are presented in such a way that hour by hour changes in the rate of community photosynthesis or respiration are readily apparent. Total community metabolism during either the light or dark period can easily be computed for comparison with the older methods.

The method used was that of Beyers, 1962a, in which changes in concentration of total carbon dioxide were measured using the relationship between dissolved carbon dioxide and pH (Beyers and Odum, 1959, 1960; Beyers et al., 1963). This method involves the use of recording pH meters to determine the diurnal variation in the pH of the microcosm water. A sample of water from the ecosystem is bubbled with nitrogen or any other inert, carbon dioxide-free gas to raise the pH. The sample is then titrated with distilled water saturated with carbon dioxide under approximately one atmosphere pressure using a tonometer burette. This procedure is essentially a titration with gaseous carbon dioxide using distilled water as a carrier, and it establishes the relationship between pH and total carbon dioxide. If this relationship is known, any change in pH can be translated into change in concentration of total carbon dioxide. The titration curve and the diurnal pH changes are the data from which the diurnal rate of change curve is constructed. The accuracy of this method varies with the chemical composition of the water but is generally ± 0.01 millimole carbon dioxide per liter per twelve hours (Beyers, 1962a; Beyers, et al. 1963).

The microcosms were under two different light and temperature regimes. Six different types of systems were in a constant temperature room under controlled temperature and a twelve hour photoperiod with constant artificial light (Fig. 1-3). These six systems were:

- 1) The twelve freshwater benthic systems investigated by Beyers, 1962a and b.
 - 2) A marine algal mat containing *Lyngbya*, *Oscillatoria*, *Desulfovibrio*, and purple sulfur bacteria. This work was done by Mr. Neal Armstrong of the Institute of Marine Science.
 - 3) A microcosm taken from the Mimbres Hot Springs, Mimbres, New Mexico, by Dr. Austin Phelps of the University of Texas, and kept in a constant temperature bath at 51° C. This community contained *Phormidium*, *Oscillatoria*, and *Anabaena*.
 - 4) A temporary pond type microcosm containing material from the vernal ponds on top of Enchanted Rock, Llano, Texas, and measured midway between filling and drying. The principal organisms in this system were cladocera, ostracoda, and small green flagellates.
 - 5) A brine microcosm taken from the Salina Fortuna salt evaporating ponds near La Parguera, Puerto Rico, and containing *Artemia* and *Dunaliella*.
 - 6) Twenty *Chlorohydra* of the strain of Eakin, 1961, in 0.6 ml of artificial medium.
- The other three systems (Fig. 4) were under natural light and varying temperatures in various outdoor situations. These three systems were:
- 1) A concrete pond containing an artificial oyster reef. The principal members of this community were *Crassostrea*, *Brachidontes*, *Menippe*, gammarids and a small green flagellate. This microcosm was initially seeded from Aransas and Copano Bays, Texas.

2) A small isolated coral head (*Millepora*) placed in a transparent chamber and cooled with running sea water.

3) Two small isolated coral heads (*Porites*) under similar circumstances. In these latter two cases, the coral heads were taken from the fringing reef around Magueyes Island, Puerto Rico. This work was done at the Institute of Marine Biology, University of Puerto Rico, La Parguera, P. R. In the coral heads as well as in the *Chlorohydra*, the community consisted of the coelenterates and their symbiotic algae.

Table 1 gives a summary of the light, temperature and salinity conditions under which the various experiments were carried out. The volumes of the microcosms and a partial community composition are also shown in the table.

Results and Discussion

Metabolic Parameters. In considering the overall metabolism of a closed ecosystem, two similar but opposite processes are of importance. They are total respiration and gross photosynthesis. Total respiration is the entire heterotrophic activity of all the organisms, both animals and plants, in the system while gross photosynthesis is the entire autotrophic effort of all the primary producers in the community. Neither of these quantities are measurable in the light because they are essentially the same net chemical change proceeding simultaneously in both directions. During the day only the excess of gross photosynthesis over daytime respiration can be measured. This excess is termed net photosynthesis (P_n).

In the dark only respiration takes place. Therefore, it is possible to measure it. However, on a twenty-four hour basis the nighttime respiration (R_{ni}) is not the total respiration of the system. The respiration which takes place during the light period does not figure in the nighttime respiration. Hence we are left with two measurable quantities, net photosynthesis and nighttime respiration. The values for these two quantities for the nine different types of microecosystem studies are shown in Table 1. The figures are expressed as millimoles carbon dioxide (± 0.01) absorbed or liberated per liter of microcosm water per twelve hour light or dark period.

In a balanced steady state system, if no export or import occurs, the ratio of net production to nighttime respiration (P_n/R_{ni}) must be unity. This situation is necessitated by the fact that net photosynthesis, which is the excess of daytime photosynthesis over daytime respiration must account for the organic matter and oxygen consumed by nighttime respiration. If some temporary happening should disturb this ratio in such a manner that it becomes greater or lesser than unity an increase or reduction of the system's biomass through growth or starvation will take place and the ratio will tend to return to unity. The net photosynthesis to nighttime respiration ratios in these microcosms were close to one (Table 1), the average being around 1.1. It can therefore be assumed that these systems were very close to being balanced.

Metabolic Pattern. In an attempt to determine whether the metabolic pattern shown by the benthic systems (Fig. 1) was of a general nature, several other microcosms of various types were measured under similar conditions. They were the algal mat community, hot spring community, the temporary pond community and the brine community. Representative curves of these four microcosms are given in Fig. 2. The same type of metabolism is shown by all four systems. The most extreme cases are in the hot spring

TABLE 1
Resume of conditions and total rates of net photosynthesis and nighttime respiration for eight types of aquatic microcosms

Type of microcosm	Light in foot candles	Temperature °C	Partial community composition	Salinity in ‰	Volume in liters	Net photosynthesis mMCO ₂ /L per 12 hr. (± 0.01)	Nighttime respiration mMCO ₂ /L per 12 hr. (± 0.01)	P _R /R _{nl}
Algal mat microcosm	1000 constant	14	<i>Desulfovibrio</i> , <i>Lyngbya</i> , <i>Oscillatoria</i> , purple sulfur bacteria	34	0.166	0.80	0.69	1.16
51° microcosm	784 constant	51	<i>Phormidium</i> , <i>Oscillatoria</i> , <i>Anabaena</i>	0	4.020	0.28	0.28	1.00
Temporary pond microcosm	850 constant	22	Cladocera, ostracoda, small green flagellates	0	4.000	0.17	0.11	1.47
Brine microcosm	467 constant	23	<i>Artemia</i> , <i>Dunaliella</i>	188	2.030	0.29	0.26	1.12
Mean of benthic systems	1000 constant	23	<i>Vallisneria</i> , <i>Oedogonium</i> , <i>Sutroa</i> , <i>Physa</i>	0	3.000	0.20	0.17	1.18
Green hydra	1000 constant	23	<i>Chlorohydra</i> and symbiotic algae	0	0.0006	1.12	1.14	0.98
Oyster pond	0-8200	30-35	Oyster reef fauna and small green flagellates	18	5930.000	0.19	0.13	1.46
Coral (<i>Millepora</i>)	0-8300	26-29	<i>Millepora</i> and symbionts	32	0.400	0.44	0.42	1.03
Coral (<i>Porites</i>) #1	0-8300	26-29	<i>Porites</i> and symbionts	34	0.385	0.49	0.38	1.28
#2	0-8300	26-29	<i>Porites</i> and symbionts	32	0.305	0.31	0.37	0.87

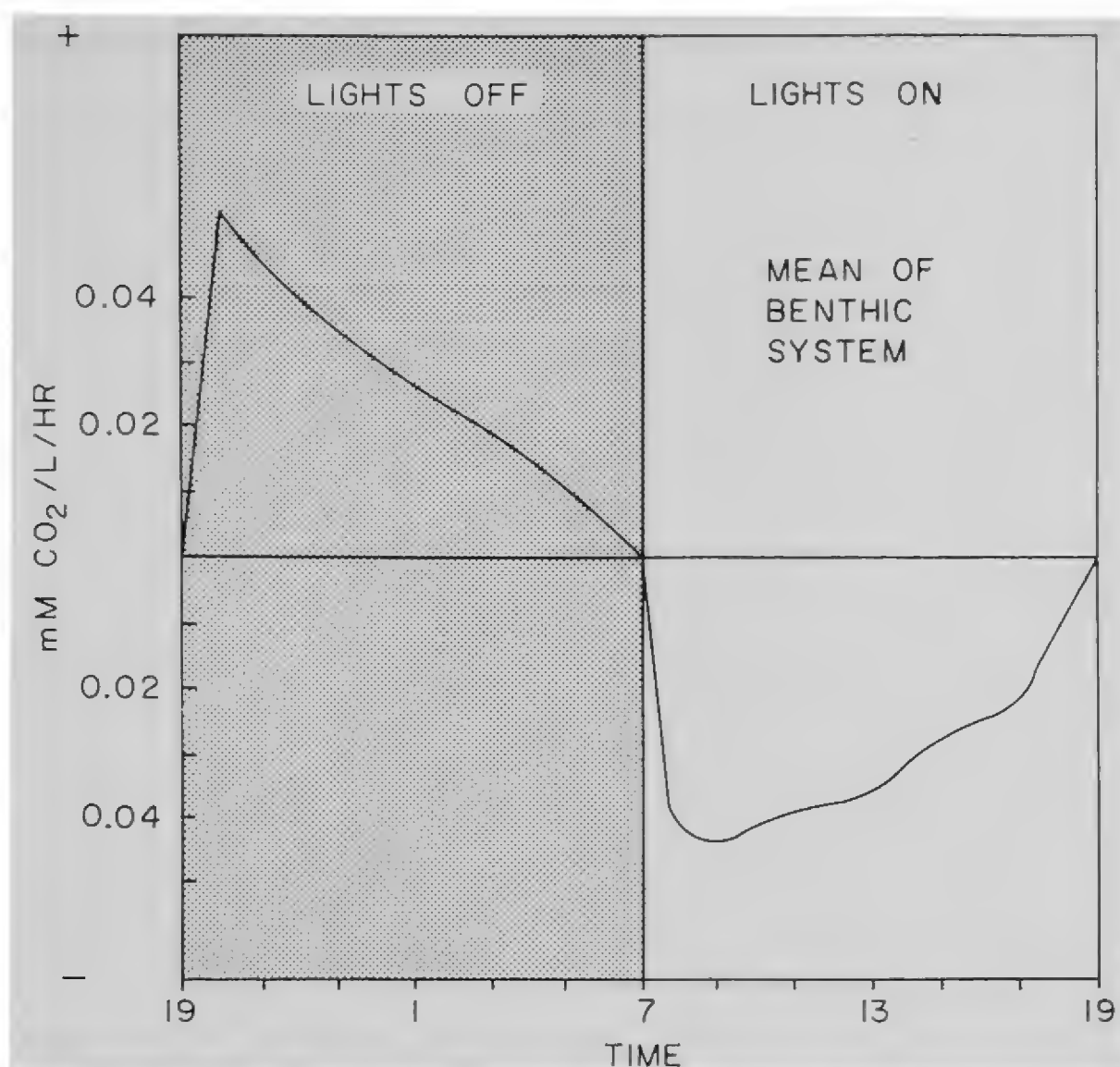


FIG. 1. Diurnal rates of carbon dioxide uptake and release during net photosynthesis and night-time respiration in twelve benthic freshwater microcosms. This curve is the mean of one hundred curves. (Redrawn from Beyers, 1962a.)

(51° C. microcosm) and brine microcosms which are also the simplest communities. However, the algal mat and the temporary pond also show decreasing metabolism as either the day or night progresses. These latter two microcosms are much more complex systems in terms of species variety than the hot spring or brine microcosms.

Among the simplest of ecosystems is the one represented by the green hydra (*Chlorohydra*). It consists of the hydra and its symbiotic algae. When measurements of *Chlorohydra* metabolism are treated in the same way as metabolic measurements of other ecosystems the same pattern becomes evident (Fig. 3). However, in this case the maximum photosynthesis occurs within two hours after lights on or lights off.

Fig. 4 demonstrates the shape of the carbon dioxide diurnal rate of change curves under a natural bell-shaped light curve. All of the curves in Figs. 1–3 were taken under a square-shaped curve of artificial light. In these outdoor systems, the same type of respiratory pattern is indicated. However, the photosynthetic pattern is affected by the changing light. Maximum net photosynthesis usually occurs in the morning even though the light reaches its maximum around noon. There is also an excess of respiration over photosynthesis in the late afternoon, resulting in a negative rate of net photosynthesis.

The photosynthetic pattern under constant illumination corresponds closely to the results of Doty and Oguri, 1957; Yentsch and Ryther, 1957; and McAllister, 1963 for marine planktonic systems. The pattern under natural illumination is corroborated by Verduin, 1957, for the planktonic systems in Western Lake Erie, by Copeland, Butler, and Shelton, 1961, for Theta Pond, Oklahoma, and by Copeland and Dorris, 1962, for oil re-

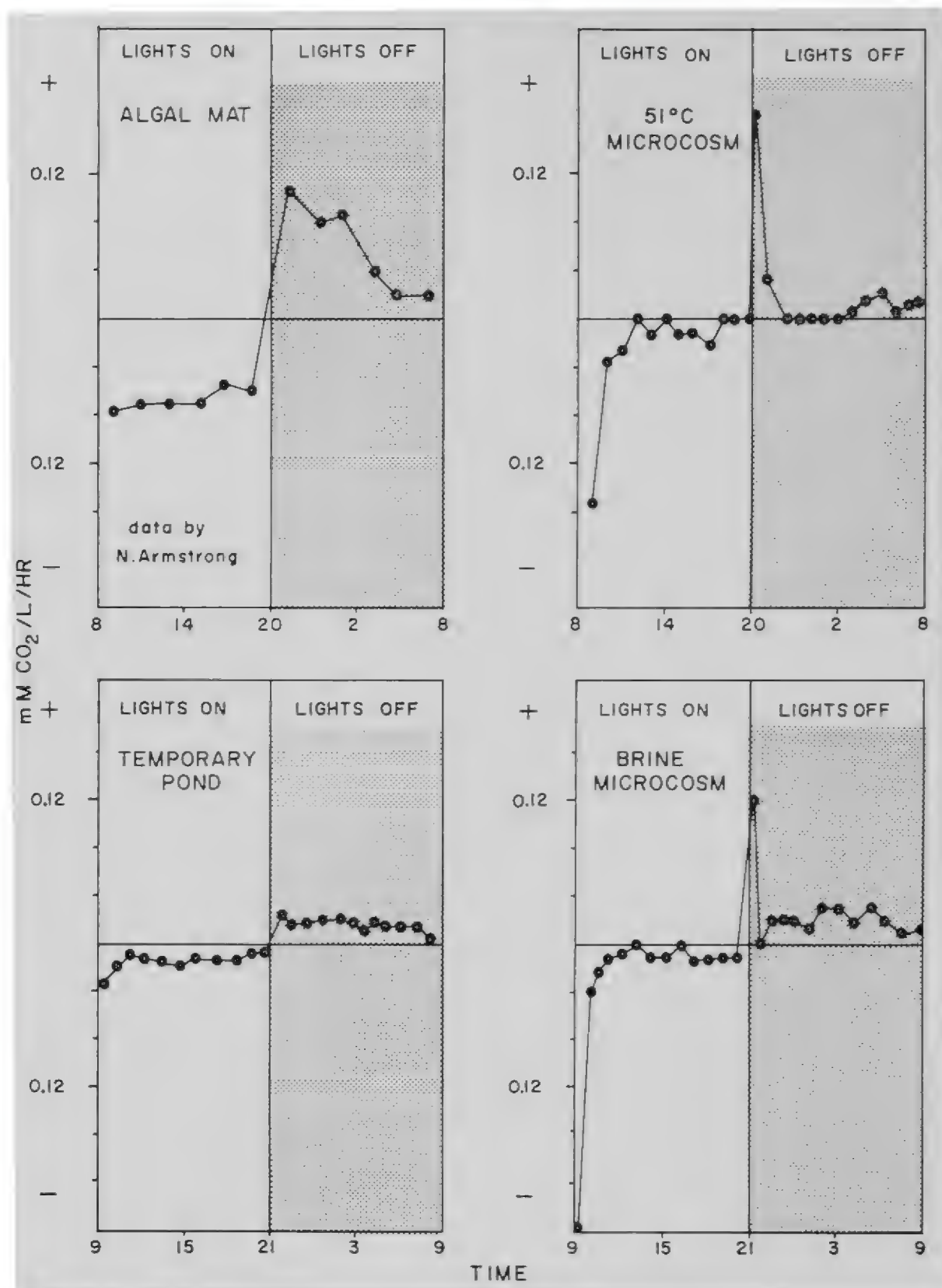


FIG. 2. Diurnal rates of carbon dioxide uptake and release during net photosynthesis and nighttime respiration in a marine algal mat microcosm, a hot spring microcosm, a temporary pond microcosm, and brine microcosm.

finery effluent holding ponds. The decreasing nighttime respiratory rate in natural aquatic systems is demonstrated by Jackson and McFadden, 1954, for Sanctuary Lake and by Park, Hood and Odum, 1958, in four out of seven of their carbon dioxide diurnal rate of change curves for several Texas bays.

It must be remembered when considering the photosynthetic pattern that these curves (Fig. 1-3) represent net photosynthesis. That is, they are graphs of the difference between gross photosynthesis and daytime respiration. Several hypotheses may be postulated to explain the shape of these curves. First, gross photosynthesis may be constant under constant illumination while daytime respiration increases during the day. In fact,

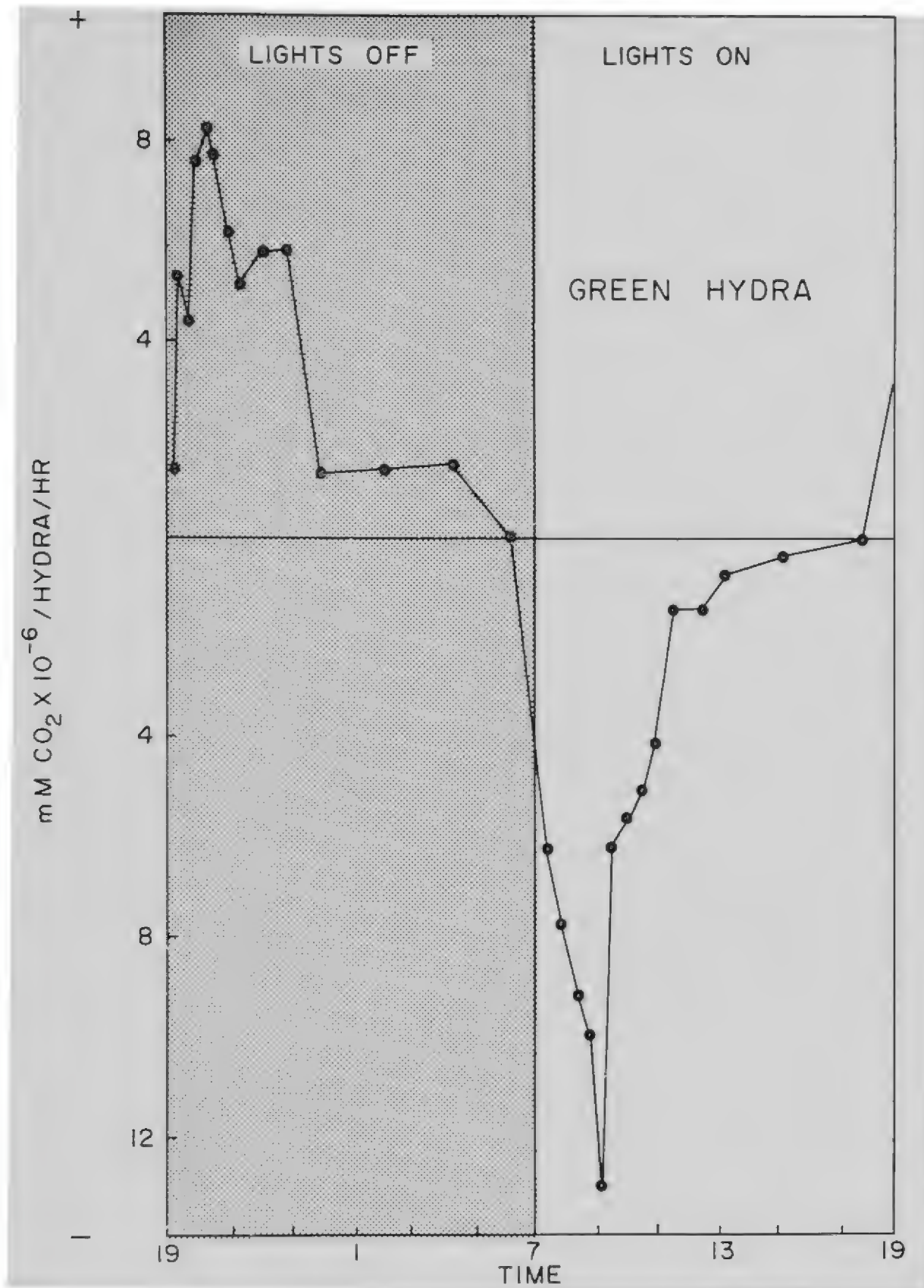


FIG. 3. Diurnal rates of carbon dioxide uptake and release during net photosynthesis and night-time respiration in *Chlorohydra*; based on twenty specimens in 0.6 ml of water, results expressed as metabolism per hydra.

daytime respiration could increase to a level almost equalling gross photosynthesis and thus account for curves of the shape of the brine microcosm or the 51° microcosm (Fig. 2) or it could exceed gross photosynthesis in the late afternoon, accounting for the shapes of the curves in Fig. 4. Second, the gross photosynthesis may decrease during the day while the daytime respiration remains constant, or third, the daytime respiration may increase while the gross photosynthesis decreases during the course of the light period. Since gross photosynthesis and daytime respiration occur simultaneously, it is not possible at present to test these three hypotheses to determine which is correct. How-

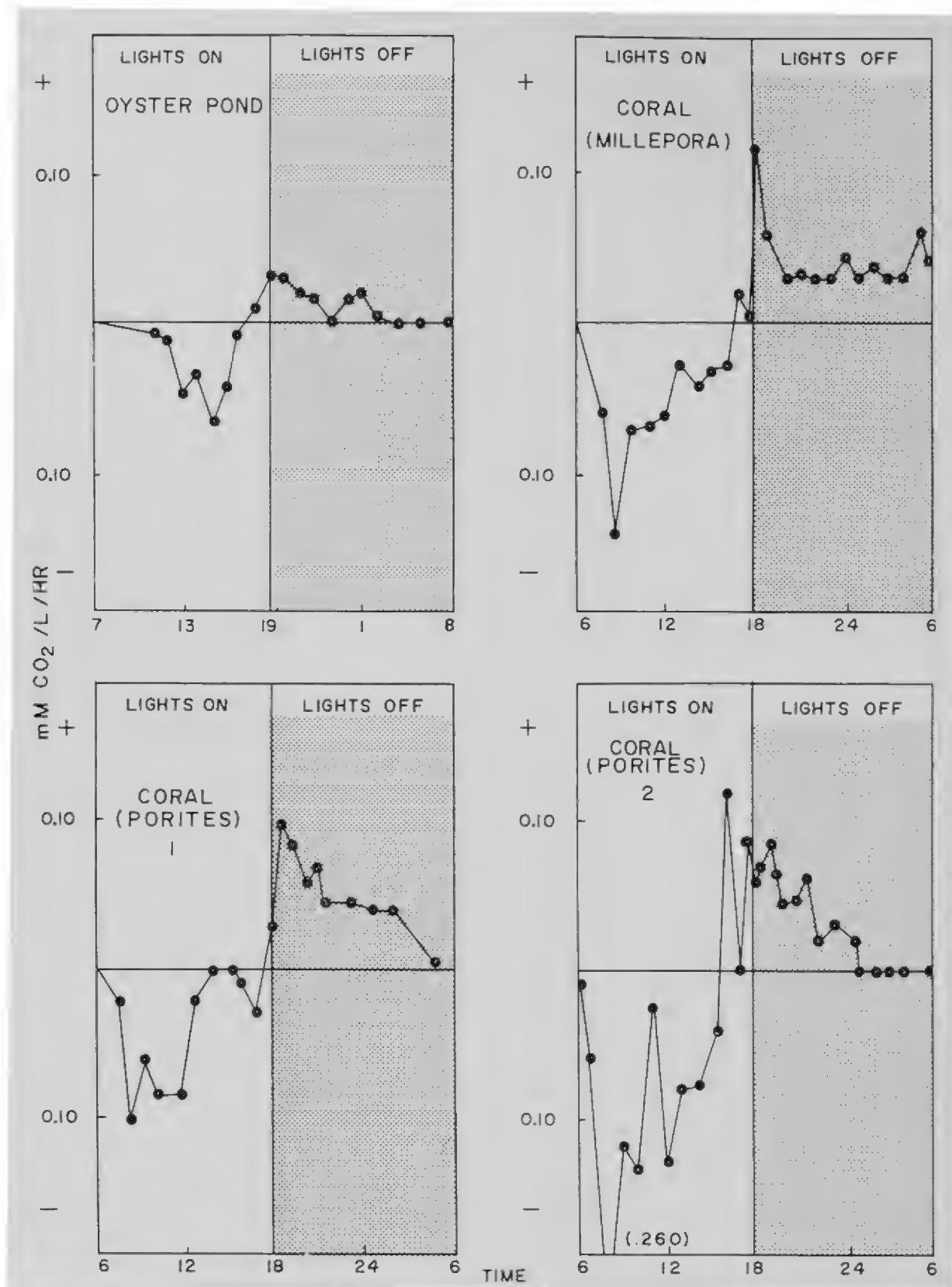


FIG. 4. Diurnal rates of carbon dioxide uptake and release during net photosynthesis and nighttime respiration in an oyster pond microcosm and in three small, isolated coral heads.

ever, it can be demonstrated that nighttime respiration does not remain constant (Fig. 1-4) and since nighttime respiration is not static there is no reason to assume that daytime respiration stays constant. This situation casts doubt on the validity of the second hypothesis mentioned above.

Further discussion regarding the shape of these curves in relation to labile fuel and oxygen, increasing carbon dioxide concentration, and inherent metabolic rhythms may be found elsewhere (Beyers, 1962a). The similarity between microcosm metabolism curves under artificial light and electrical analogue circuits set up as theoretical models relating metabolic rates to storage accumulations has been pointed out by Odum, Beyers, and Armstrong, 1963. The data obtained in the present study are reported here because

they extend the earlier observations on the changing metabolic rates in larger aquatic ecosystems.

Acknowledgments

I would like to thank Dr. Juan A. Rivero and Dr. John Randall for research facilities at the Institute of Marine Biology, University of Puerto Rico, Mayaguez. Some of the data used in this study were obtained by Mr. Neal Armstrong and Mr. Bill Gillespie. Dr. Austin Phelps of the University of Texas collected the material for the hot spring microcosm. Drawings by Mr. Bill Gillespie.

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Cobalt, Iron, and Manganese in a Texas Bay¹

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Abstract

The concentrations of cobalt, iron and manganese were determined in the water, sediments, underwater plants and animals predominating in the grass flats of Redfish Bay, a shallow marine estuary near Port Aransas, Texas. All three elements were greatly concentrated in sediment and organisms with respect to sea water. The concentrations were multiplied by estimates of dry weight of the principal components per square meter of bay to obtain an inventory of the grass flat. The plant *Diplanthera wrightii* is outstanding in that it accounts for much of the inventory of all three elements in the community (2.3 mg/m² Co, 627 mg/m² Mn and 422 /mgm² Fe). All chemical determinations were spectrophotometric. An appropriate gamma emitting radioisotope of each element was used to check the chemical procedure and to correct for chemical yield. A new method for the removal of manganese and cobalt from sea water by lanthanum hydroxide precipitation was developed.

Introduction

The concentration of zinc in sea water, sediment and a variety of marine organisms as well as the zinc inventory for Redfish Bay were reported by Parker (1962). The present work extends this study of trace elements to include cobalt, iron and manganese. All four elements are of biological importance in the sea yet are present in only trace quantities. Since the organisms living in the bay require several thousand times more trace elements than is contained in the water column, some mechanism must be available to return the trace element removed by dead organisms to the system. It is very probable that the concentration of some trace metals in the bay water and perhaps in the sediment are a function of the rate of removal by the organisms and rates of return from the dead organisms, especially since sea water is undersaturated with respect to insoluble compounds of several trace metals (for example zinc and cobalt) that might form from the ions normally present in aerated sea water (Krauskopf, 1956). It was felt that knowledge of the distribution of these trace elements in the various phases of a typical marine estuary would, besides pointing up some interesting facts in the comparative biochemistry of the elements studied, serve as a base for further studies of the rate of removal and return of trace elements. In the course of this work it has been possible to apply known methods of chemical analysis to marine samples and to develop some new methods.

Experimental Methods

The methods of determination for all trace elements are essentially those described by Sandell (1959) and are based on spectrophotometry. For this reason only a very brief outline will be given. Where improvements have been made, as in the use of lanthanum hydroxide to concentrate cobalt and manganese from large volumes of sea water and

¹ Supported by the United States Atomic Energy Commission through Contract No. AT(40-1) 2580.

the use of radioactive tracers for keeping up with the chemical yield, more detail is given. All biological materials were decomposed by ashing in a porcelain crucible at 500° C. All water samples were collected and filtered (0.45 micron) just before analysis.

Cobalt. Water samples necessarily had to be large; 4.5 liters were taken for each determination. After millipore-filtering a known quantity of Co^{60} was added to check the procedure and correct for losses. One hundred milligrams of LaCl_3 and enough ammonia gas to cause lanthanum hydroxide to precipitate were added—the $\text{La}(\text{OH})_3$ precipitation was repeated if the yield was less than 70%. The cobalt carried by the lanthanum was purified by the following procedure prior to determination. The hydroxide was dissolved in a minimum of 1:3 nitric acid and evaporated to near dryness on a steam bath. Nitric acid was added until the solution was clear. Sodium citrate (50%) was added to give a pH of 3–4, using methyl orange as an indicator. Five ml of a 1% w/v solution of 1-nitroso-2-naphthol were added and the solution was allowed to stand for 15–20 minutes with occasional shaking. The cobalt complex was extracted into chloroform and washed with 1:99 HCl. The chloroform extracts were evaporated to dryness on a steam bath and 1:1 HNO_3 and sodium sulfate were added to oxidize organic matter. Nitric acid was added until the sample was colorless. The cobalt was then determined in this material by the nitroso-R-salt described by Sandell (1959), using citrate-phosphate-borate buffer. The optical density was measured at 530 millimicrons using a Beckman Model B spectrophotometer.

Biological samples were ashed and the ash taken up in 1:1 nitric acid. After evaporation to dryness on a steam bath 25 ml of 1:49 H_3PO_4 was added if the sample was tissue or 25 ml of H_2O if the sample contained bone. Sodium citrate was then added and the purification procedure and determination carried out as in the sea water samples.

Sediment samples were digested in concentrated nitric acid containing a few ml of perchloric acid at boiling temperature for several hours. The acids were fumed off and the residue leached with 0.1 N HCl. Sodium citrate was added to the solution and the purification-determination procedure described above followed.

Cobalt is very low in most samples so that care must be taken and blanks run with each series of determinations.

Iron. Iron determinations were carried out using bathophenanthroline (4,7-diphenyl—1,10-phenanthroline) following the procedure given by Sandell (1959). Iron in sea water samples was measured directly without further concentration (Lewis and Goldberg, 1954). Biological and sediment samples were decomposed with nitric-perchloric acid mixtures.

Manganese. The permanganate color method was used to determine manganese (Sandell, 1959). Since it is not a very sensitive method, it was difficult to apply to sea water analysis. Nevertheless, since manganese was present in a high concentration in the organisms, the results were satisfactory. Manganese with added Mn-54 tracer was concentrated from several liters of sea water by lanthanum hydroxide precipitation as described for cobalt. Biological samples were ashed prior to determination.

Results and Discussion

Samples collected mostly from the turtle grass beds of Redfish Bay located near the Institute of Marine Science were analyzed for cobalt, iron, and manganese using the methods described. Results for the biological and sediment samples are reported on a dry

weight (110° C) basis. These results are given in Table 1. The sea water values may be compared to data in the literature. Thus the range of values found for Co in the bay and beach waters around the Institute, 0.34 to 0.9, are similar to those reported by Ishibashi (1953), 0.38 to 0.67, and Black and Mitchell (1952), 0.3, where all values are in $\mu\text{g/liter}$. The bays around the Institute are much richer in both soluble (mean 30) and particulate (mean 200) iron (as defined by 0.45 micron millipore filtration), than are the waters of the North Pacific for which Lewis and Goldberg (1954) report a mean of 3.4 for soluble and 4.5 for particulate; all values in $\mu\text{g/liter}$. This is probably due to run-off and to stirring of the sediments by the wind. Manganese in Redfish Bay ranged between 5 and 15 $\mu\text{g/liter}$, which compares well with the values of 4.5 and 6.2 determined by activation analysis (Rona, Hood, Muse, and Buglio, 1962). The three elements did not show a relation between trace element concentration and salinity. From this it is concluded that processes other than evaporation and rainfall control the concentration of these elements in the bays.

TABLE 1
Summary of chemical analyses

Sample	Co ppm	Fe ppm	Mn ppm
Local bay waters ¹	(5) 0.34—.9	(15) 5—78	(3) 5—15
Redfish Bay sediment	0.4	1000	92
Grass, <i>Thalassia testudinum</i>			
root	0.5	366	14
blade	0.34	279	173
Grass, <i>Diplanthera wrightii</i>	4.0	735	1100
Mullet, <i>Mugil cephalus</i>	0.5	178	18
Pinfish, <i>Lagodon rhomboides</i>	0.6	48	24
Fish, <i>Menidia</i> sp.	0.6	160	20
Brown shrimp, <i>Penaeus aztecus</i>	0.4	75	10
Grass shrimp, <i>Palemonetes</i> sp.	2.	285	26
Crab, <i>Callinectes sapidus</i>	0.3	166	42
Jellyfish, <i>Physalia</i>	1.	....	....

¹ The water concentrations are in parts per billion. The number in parenthesis gives the number of samples between the ranges given.

Table 1 shows that all the organisms are greatly enriched in all three of the trace metals compared to sea water. This is the usual observation for trace elements in marine organisms (Fukai and Meinke, 1959). The exact significance of such concentration factors is not known. The amount of trace metal in a given organism must be related to specific biochemical needs of the organism. But to understand the requirements of even one organism for one metal is a major problem which is beyond the scope of this paper. The value of data such as Table 1 is to point out the comparative behavior of different organisms toward different elements. For example, it is interesting that the plant *Diplanthera wrightii* contains more Co, Fe and Mn than any other organism studied. The relatively high cobalt content of the grass shrimp, *Palemonetes* sp., suggests that this easily grown and very abundant animal deserves further study.

The inventory of Co, Fe and Mn given in Table 2 was the main reason for the present study. Quantitative knowledge of the distribution of these representative trace metals gives some insight into the behavior of these elements in a bay. Similar data has been published for zinc (Parker, 1962). Table 2 indicates that the amount of trace element held in the water column is negligible compared to that held in the organisms. Thus, for

TABLE 2
Cobalt, iron and manganese inventory for a grass flat

Sample	Description	Dry weight ¹ g/m ²	Co mg/m ²	Fe mg/m ²	Mn mg/m ²
Bay water	1 m depth	1×10^6	0.5	30	5
Sediment	per cm depth	1×10^4	4.0	1×10^4	920
<i>Thalassia</i>	summer crop				
roots		2800	1.4	1×10^3	39
blades		200	0.07	74	34
<i>Diplanthera</i>	summer crop	568	2.3	422	627
Mullet	max biomass	2.3	1×10^{-3}	0.4	4
	min biomass	0.06	3×10^{-5}	1×10^{-2}	1×10^{-3}
	avg biomass	0.6	3×10^{-4}	1×10^{-1}	1×10^{-2}
Pinfish	avg biomass	0.18	1×10^{-4}	9×10^{-3}	4×10^{-3}
Crab	max biomass	1.5	5×10^{-4}	3×10^{-1}	6×10^{-2}
Brown shrimp	max biomass	0.07	3×10^{-5}	5×10^{-3}	7×10^{-4}

¹ Dry weight values for animals were taken from Hellier (1962), others were measured.

this system the function of water must be one of transport, not of supply. The inventory shows that the amount of metal in the biosphere (plants and animals) is almost the same as that in the top cm² of the sediment for Zn, Co, Fe and Mn. This suggests that the central problem in the biogeochemistry of these elements in this bay is the rate of movement from sediment to biosphere. It is especially important to have some estimate as to how much of the sediment, measured from the water sediment interface down, is involved in the cycle.

A few measurements of the rate of movement of radioactive tracer into the sediment were made to get some feeling for this. Small cores of sediment with overlying water column were brought to the laboratory, tracer added, and the water stirred slightly by a bubble tube. There was a smooth loss of tracer from the water in all cases, with a half-time of a few hours. However, when the cores were frozen and sliced, it was found that the tracer had only penetrated the sediment 0.5 to 1.5 cm in 10 days. These preliminary results suggest that only the top few cm are important in the day-to-day cycle of these elements.

It appears that a fine balance of these four elements is maintained between the plants and animals of the grass flat and the sediment. Since the turnover of carbon in the system is known to be large (Odum and Wilson, 1962) it is probable that there is a fairly rapid turnover of these elements. Since the amount of trace metal used by the system appears to be about the same as that available to it, depletion in trace metal cannot be ruled out as a factor in the productivity of the grass flat.

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Radioactive Fallout in *Sargassum* Drift on Texas Gulf Coast Beaches¹

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Abstract

In the spring and early summer of 1962 a large amount of seaweed (*Sargassum*) was washed up on the beaches of the northern Gulf of Mexico. The *Sargassum* heaps were weakly radioactive due to the presence of fallout. The radio-active elements from fallout (gamma emitters) included cerium, ruthenium, and zirconium-niobium. Beta radiation from the accumulated seaweed was roughly comparable to the total atmospheric precipitate during February over an area of approximately 800 to 1300 square miles in the Gulf of Mexico.

From early March through early July, 1962, large amounts of *Sargassum* were washed ashore on the northern Gulf Coast. This accumulation formed a continuous mat 50 to 100 feet wide which extended about 260 miles along the Texas coast from Sabine Pass to Corpus Christi diminishing to negligible amounts at Port Mansfield and Brownsville. It was reported from various points along the Gulf Coast beaches and barrier islands as far east as Miami, Florida. When fresh, the weed rows had a maximum thickness of about 1½ feet. When dry the thickness was about 6 inches. Staff of the Institute reported that *Sargassum* was brought ashore with the first southeast winds during March and April each year, but the 1962 deposits were by far the largest at least since 1954. The cause of the bumper crop of 1962 is not known, but it has been speculated that hurricane Carla the previous year may have been a major factor in changing the nutrients patterns of the Gulf surface waters. While the writer and Dr. Peter U. Rodda, Bureau of Economic Geology, The University of Texas, were making a field survey for radioactive sands in May, the beach rows of seaweed were found to have significant radiation relative to background.

Two localities were studied in detail: (1) the beach on Mustang Island near Port Aransas, Texas, and (2) the beach on Galveston Island about 6 miles west of Galveston. In both places the weed was sampled, and a radiometric survey was made over a section of the weed-covered beach using a hand-carried scintillation counter. The radiation profile at the two localities was almost identical. Background was 0.006 to 0.008 mr/hr, and the readings over the thickest parts of the weed beds were 0.016 to 0.017 mr/hr. Variations in radiation followed the variations in thickness of the piles of weed very closely. Fig. 1 is a field map of scintillometer readings of gamma radioactivity from the heaps of beach *Sargassum*.

Channels one foot wide were cut across the weed beds, and the weed removed was weighed to find a tonnage factor per mile along the coast. Because part of the weed was wet, the wet and dry parts were weighed separately. After a dry-wet ratio had been de-

¹ This study was made as part of a research course, Marine Science 380.1 at the University of Texas Institute of Marine Science with Howard T. Odum, Albert Story, and William Behrens assisted by AEC Contract AT-(40-1)-2580.

² On summer leave from the Bureau of Economic Geology, The University of Texas, Austin.

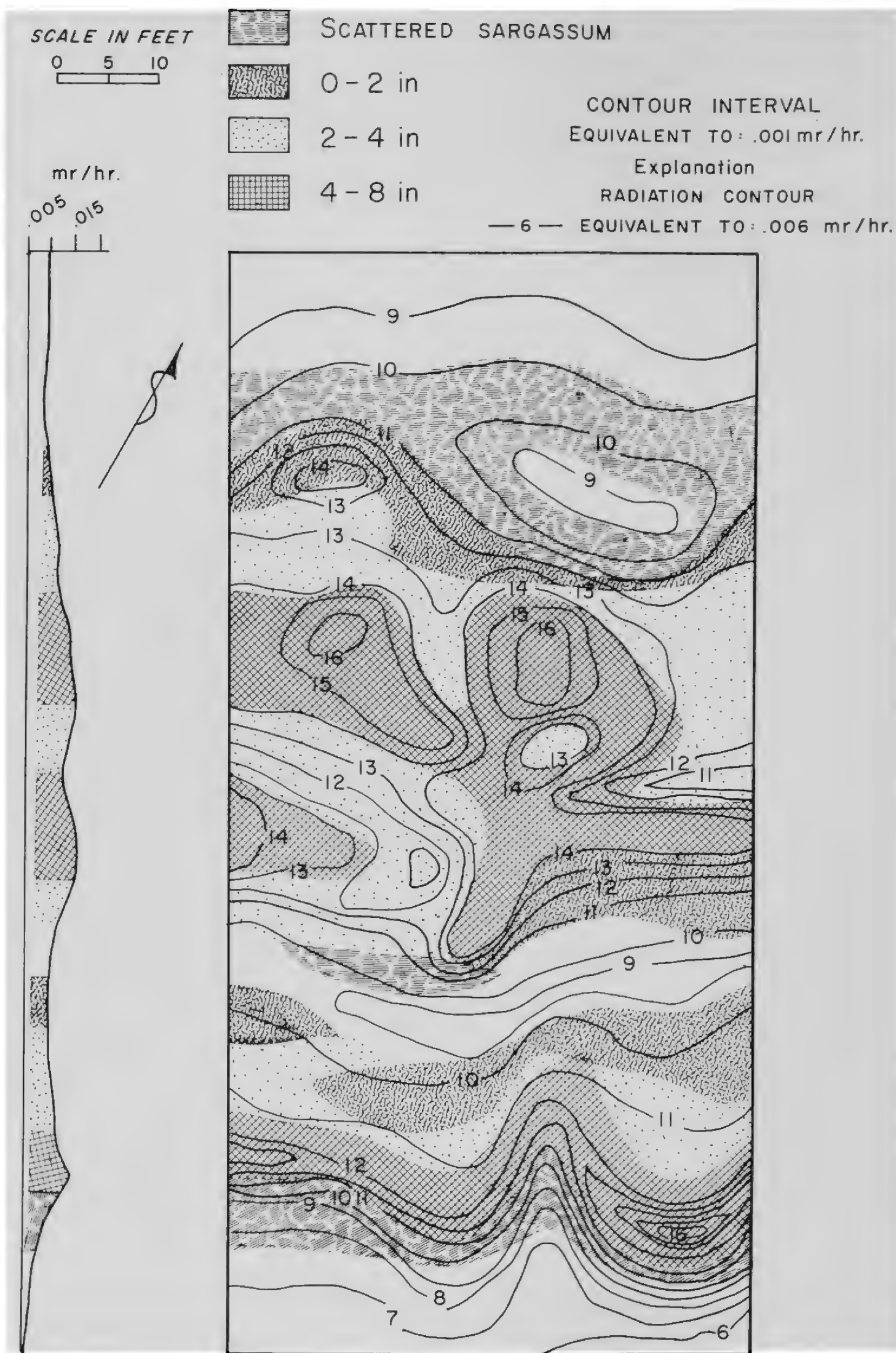


FIG. 1. Contour map of radiation values in milliroentgens per hour on a section of *Sargassum* covered beach 6 mi SW of Galveston, Texas; July, 1962; shaded areas indicate thickness of *Sargassum*. Profile at left is from the extreme left side of large section. Arrow points north.

terminated, the appropriate correction was applied to the wet weight. The corrected weights of weed are:

Galveston:	150 lbs/ft, or 397 tons/mile.
Port Aransas:	85 lbs/ft, or 225 tons/mile.

The radiation survey and thickness measurements at Port Aransas were made in June while a considerable amount of weed was still being brought ashore. At this time the mat of *Sargassum*, representing deposits over a 3-month period, was in all stages and conditions between fresh weed and partly decomposed dry weed. The weed was not weighed at this time for two reasons: (1) as long as fresh weed continued to come in, any weights taken would not represent the total accumulation; and (2) it would have been impossible to rationalize the differences in weight between dead dry weed, fresh weed, and dead water-soaked weed. It was also considered that if any sizable amount of weed were brought in later, the radiation survey at Port Aransas could be repeated. As it happened, the influx of weed dropped off as the strong winds abated soon after the June survey so that later checks with the scintillator showed no significant change in the level of radiation at the Port Aransas locality.

When the weed was weighed at both localities (July), it was almost uniformly dry, and the part that was wet, just behind the berm, was considerably decomposed. Also, the part of the weed nearest the Gulf had been buried by sand due to wave action and was too decomposed to be shaken clean and weighed. For this reason, it is believed that the figures given here represent minimum values and that the total weight of weed and radioactivity brought ashore was actually somewhat greater.

A sample of *Sargassum* from Port Aransas was analyzed by the U. S. Public Health Service at the Robert A. Taft Sanitary Engineering Center in Cincinnati, Ohio. The gamma spectrum was plotted on a 512 channel analyzer. In the report of this test, Dr. Albert G. Friend, chief of the Cooperative Studies Unit, Division of Radiological Health, said, "... it appears that all the activities associated with the sargassum weed are due to fallout materials."

The results of a 40-minute count of a dry sample weighing 20.6 grams were:

Ce ¹⁴⁴ :	300 micromicrocuries/sample, or 14.5 micromicrocuries/gram
Ru ¹⁰⁶ :	150 micromicrocuries/sample, or 7.3 micromicrocuries/gram
Zr ⁹⁵ -Nb ⁹⁵ :	720 micromicrocuries/sample, or 34.9 micromicrocuries/gram

Total: 56.7

Not counting beta emitters and lesser contributors, there was at least 51.4 microcuries per ton.

To make a rough comparison between the fallout rate reported in gross beta activity and total amount of radioactive material in the seaweed on the Texas beaches, a sample of the weed at Port Aransas was ashed, and beta count was made. This test showed beta activity of 1400 micromicrocuries per gram of dry ash, or 1.27×10^3 microcuries per ton of weed, based on a rough efficiency estimate of 20%.

In making an estimate of the total amount of radioactive material cast up on a 260-mile segment of the Texas coast, computations were made, based on the Port Aransas data and the Galveston data. The true figure probably lies somewhere between these extremes.

Basis of computation	Total weed dry	Total fallout material	
		(Gamma)	(Beta)
Port Aransas	58,000 tons	2.98 curies	73.66 curies
Galveston	95,000 tons	4.88 curies	120.65 curies
Port Isabel (near Brownsville)	trace	trace	trace
Port Mansfield (between Browns- ville and Corpus Christi)	trace	trace	trace

Published data of the U.S. Department of Health Education and Welfare (Radiological Health Data, 3(5) May, 1962) show that for the month of February, 1962 (the month preceding the influx of the weed), three stations bordering or near the northern Gulf of Mexico reported gross beta activity in atmospheric precipitation as follows:

Pascagoula, Miss.	36,000 micromicrocuries/meter ²
Austin, Texas	44,000 micromicrocuries/meter ²
New Orleans, La.	84,700 micromicrocuries/meter ²

Using the Pascagoula figures, this is equivalent to approximately 93,600 microcuries per square mile. Combining this with the Port Aransas computation for total radioactive material (beta activity) along the 260-mile segment of the coast, it is apparent that the radioactive material cast up on the Texas coast in *Sargassum* is roughly equivalent to the total atmospheric precipitate during February over an area of approximately 800 square miles in the Gulf of Mexico, or, based on the Galveston computation, approximately 1300 square miles. Computations based on the New Orleans fallout rate would show comparatively smaller areas of equivalent precipitation.

These calculations, although highly speculative, do offer a general indication of the ability of *Sargassum* to concentrate large proportions of the fallout materials from sea water of the open Gulf and bring it up on the beaches.

Acknowledgments

The writer is indebted to the University of Texas Bureau of Economic Geology for the use of a scintillometer; to Dr. Sammy Ray and the Galveston Marine Laboratory of the Texas A. & M. College for overnight accommodations and use of a field vehicle; to Dr. Albert G. Friend and staff at the Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, for performing a multi-channel analysis of the gamma spectrum of a sample of *Sargassum*.

Seasonality of Larger Animals in a Texas Turtle Grass Community¹

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Abstract

A one-year study was made of macro-invertebrates and fishes in the grass flats of Redfish Bay, Texas, using a drop-net quadrat. The major invertebrate was *Penaeus duorarum* and the major fish *Lagodon rhomboides*. Population levels of nearly all species suddenly increased to high levels and decreased as rapidly to former low levels. Heaviest populations occurred in spring (4.9 gm/m² in May) with a secondary high in fall (3.5 gm/m² in mid-September and October). Lowest populations occurred in summer (0.8 gm/m² in mid-July to mid-August) and winter (0.46 gm/m² in January). Total population densities were correlated best with water level, but summer and winter minimums coincided with many adverse factors. The fauna was similar to that of Florida west coast bays where the major habitat type is the same.

Introduction

Recently a drop-net quadrat method was developed for quantitative sampling of larger motile forms in shallow marine waters (Hellier, 1958; 1962). The method was described in detail in these papers along with a literature review. Hellier's work was on a *Diplanthera* community in the hypersaline Laguna Madre.

During 1962 a similar study was made in the very shallow, dense grass-flats in Redfish Bay (Fig. 1). The bottom of this bay was covered with large expanses of *Thalassia testudinum*, which was gradually replaced in the shallows by *Diplanthera wrightii*. Red algae were common, interspersed among the grasses, especially *Gracilaria*.

Since Redfish Bay is close to the Gulf of Mexico and lacks any fresh-water drainage system, it has relatively constant salinity. Salinities of 22–25‰ were encountered in spring and 39–41‰ in summer, 1962.

Redfish Bay is so shallow that small changes in tide greatly change the water volume. Seasonal changes in average sea level (Marmer, 1954) lowered water levels from spring and fall depths of over 0.5 m to less than 0.3 m in summer and winter. Sometimes tides were so low the bay bottom was partly bare. During these conditions many factors became extreme. For example, on the afternoon of August 8 with 25 cm of water, temperatures reached 36° C, although temperatures of the bay bottom were 32° C and 8 cm below were 30° C. The bay was subject to wide temperature changes which reached extremes over 35° C in July and August, 1962 (Fig. 3). Odum and Wilson (1962) reported that oxygen levels fell below 1 mg/liter at night on 7 July 1959, even though they were over 10 mg/liter the previous afternoon at temperatures of 39° C.

Considerable published data are now available on Redfish Bay. Ladd (1951) first studied the bay and listed several molluscs. Hildebrand (1954) reported *Lagodon*

¹ Work supported by the Texas Game and Fish Commission through interagency contract 4413–578, Dr. H. T. Odum, principal investigator.

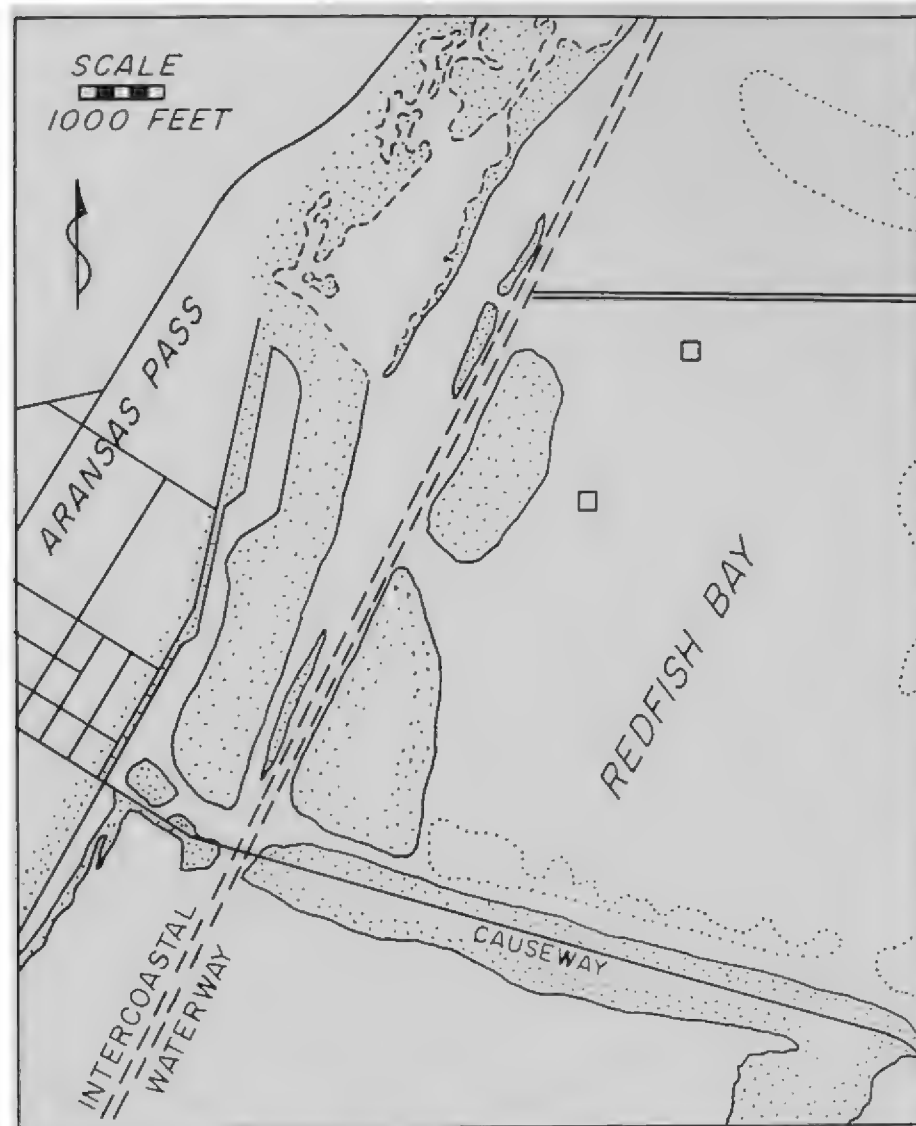


FIG. 1. Map of Redfish Bay; squares show location of quadrats.

rhomboides, *Orthopristis chrysopterus*, *Gobiosoma robustum*, *Syngnathus scovelli*, and *S. floridae* as the common Texas grass-flat fishes. A number of productivity studies have been conducted by the Institute of Marine Science, the latest by Odum (1963). Volkman and Oppenheimer (1962) studied organic carbon deposition, while Hellier and Kornicker (1962) followed sediment deposition during dredging of the Intracoastal Waterway.

Methods

Samples were taken with a drop-net suspended from piling placed at two stations in *Thalassia* beds in Redfish Bay (Fig. 1). The drop net suspended above the water covered an area of 118 m². After the net was released the enclosure was seined with a 20 foot common sense minnow seine. Sampling was all done during daytime except for one early evening drop June 11.

Several difficulties were encountered in this study which Hellier (1962) did not find in the Laguna Madre. Because of the soft mud, seining disturbed the habitat even though sampling was alternated between sites. Many specimens too small to be entrapped by the drop-net mesh (19 mm stretched mesh) were not sampled. Therefore, these populations were underestimated. We feel that in such habitats a portable net would be more practical and accurate.

Collections were made once or twice monthly and the data obtained presented in numbers and grams wet weight. We did not include some large sporadically occurring species

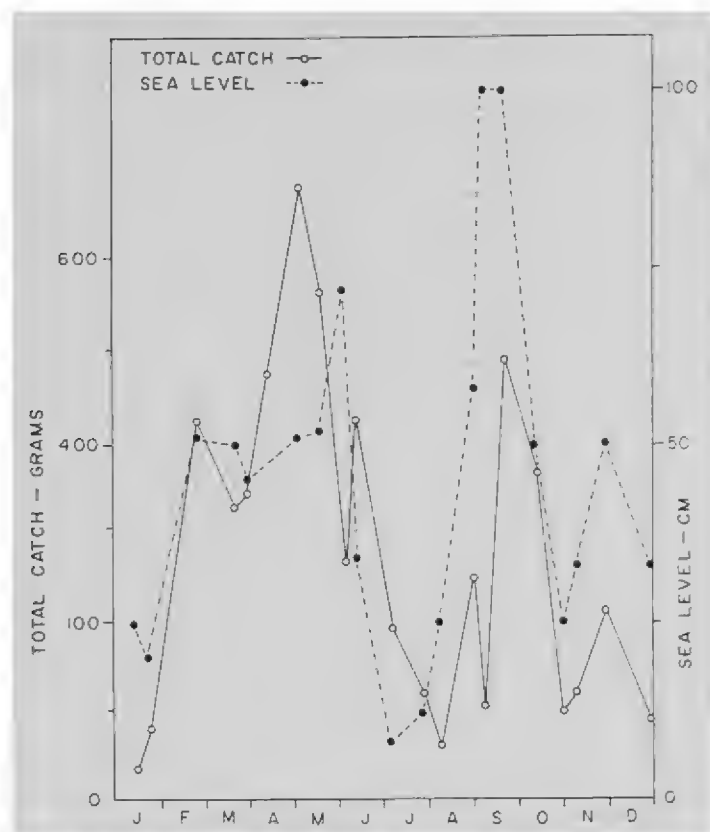


FIG. 2. Total biomass (excluding larger species) correlated with bay water level at time of sample. 100 gms = 0.85 gms/m² in all graphs.

in the total biomass curves (Fig. 2) because they were inadequately sampled. Annual totals for both *Opsanus beta* and *Mugil cephalus* were 0.22 gm/m². One of these, *O. beta*, actively sought the bases of the quadrat piling.

Results

The results of the annual cycle of sampling are given in the biomass graphs of Figs. 2-8 and in Table 1. Total catch, without the forementioned exceptions, is compared with bay water level at time of sampling (Fig. 2). The components of this catch are discussed in the following paragraphs.

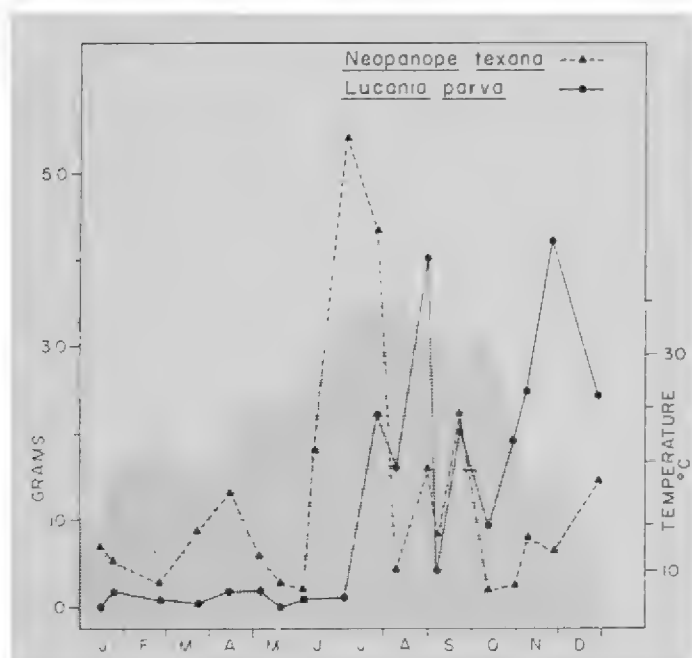


FIG. 3. Correlation of biomass of two species with temperatures at time of sample.

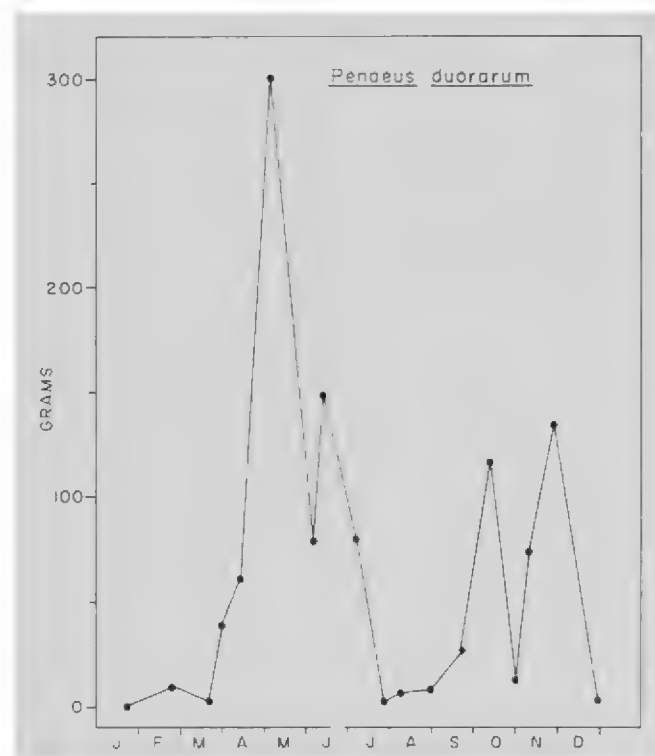


FIG. 4. Catch of pink shrimp, *Penaeus duorarum*.

PINK SHRIMP

Penaeus duorarum was the characteristic large Redfish Bay invertebrate. It was the only penaeid shrimp taken from the bay. This is amazing habitat specificity in view of the abundance of related *P. aztecus* in adjacent bays (Gunter, 1950, and others). A population peak was reached on May 4, after the sudden appearance of large numbers of small shrimp in late March (Figs. 4, 9). Large juveniles and sub-adults disappeared in June, which is when large numbers of migrating pink shrimp have been caught in the inlet at Port Aransas in some years. During the hot summer months few shrimp were taken, but in October and November catches rose somewhat. Shrimp were scarce in winter but very small juveniles were taken as late as December 27.

Smallest individuals (20–30 mm) were in the catch by early March, and continued to appear through mid-May. Except for a small amount in July, little or no recruitment occurred from early June until well into August. A second wave of young entered in late August through late November.

The large peak reached in May seems to be from growth of the largest influx of young in early April. Emigration of this group in late May and June left a smaller population from the small May recruitment. By June, recruitment stopped and nearly all shrimp soon reached emigration size (over 60 mm) leaving few to remain during the severe summer. The immigration of post-larval pinfish similarly stopped long before severe conditions began in July. Some mechanism seems to stop recruitment early preventing high densities when severe conditions begin.

Since *P. duorarum* recruitment was constant, tracing size groups was difficult but apparently shrimp under 30 mm in March reached 65–75 mm by early May, and those under 30 mm in late August reached the same size by mid-October. These data suggest a growth rate close to 1 mm a day, below that Williams (1955) reported for North Carolina *P. duorarum*.

Two-thirds of the Texas pink shrimp production comes from the Gulf opposite Redfish Bay (Gunter, 1962), one of the largest *Thalassia* communities on the Texas coast. Other small *Thalassia* communities occur in Aransas, Corpus Christi, and West Bays, and in the Lower Laguna Madre. Other areas of Redfish Bay were seined in 1962 without obtaining any species but pink shrimp.

While shrimp biologists often point out the importance of inshore nursery grounds to maintenance of pink shrimp stocks, we are not aware of emphasis on linking inshore nursery areas to grass communities as Hildebrand (1955) has stated. Perhaps this is taken for granted but Eldred et al. (1961) do not mention this and suggest that spawning temperature is most important. Hoese has collected pink shrimp in *Zostera marina* in Chesapeake Bay (see also Williams, 1955) where temperatures are lower than in Texas, a region where pink shrimp are also uncommon. A sizable fishery for pink shrimp exists in North Carolina (Williams, 1955) but they are rare in South Carolina and Georgia (Power, 1959; and several annual reports of Bears Bluff Laboratories, Wadmalaw Island, S. C.), where we have found no record of large expanses of spermatophyte communities. Williams (1955) did emphasize importance of cover for penaeid shrimp in general, but did not associate *P. duorarum* and grass in contrast to other species. Williams (1958) also found that it chose a bottom type different from two other species of *Penaeus*.

PINFISH

The pinfish, *Lagodon rhomboides*, was the most abundant fish species with the largest biomass. A very large May-June peak was followed by a July-August low and a smaller August-September peak (Figs. 8, 10). Except for the summer absence this pattern corresponds closely with Hellier's (1962) collections. Hellier (1962) sampled a slightly older and larger population from somewhat deeper waters.

Apparently post-larval pinfish entered the bay at a size of about 15 mm between February and May with largest numbers in April.

SEASONAL PATTERNS OF OTHER ANIMALS

The summer data on snapping shrimp, *Alpheus heterochaelis*, were inaccurate due to their burrowing habits. None were taken in the trap during the hot summer months, but specimens were found by digging in the bottom where temperatures were up to 7° C cooler.

For a short time in late winter and early spring, grass shrimp, *Palaemonetes pugio*, were extremely abundant (Fig. 5). Weights and counts were below actual values since very small shrimp passed through the nets. Rapid decline of the population began in March and by May they were rare. It is possible that other species occur in Redfish Bay, but specimens in the February peak were identified as *P. pugio*.

Blue crabs, *Callinectes sapidus*, reached a peak in March and April but rapidly disappeared and remained scarce throughout the study (Fig. 6). This late winter-early spring abundance and subsequent emigration has been shown by Daugherty (1952) in other bays.

Neopanope texana was the dominant mud crab in the bay. It was most abundant dur-

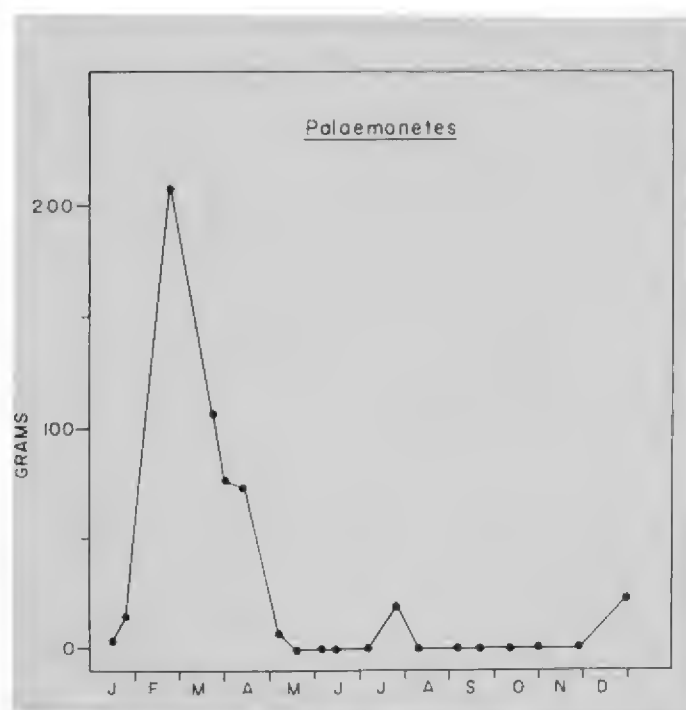


FIG. 5. Catch of grass shrimp, *Palaemonetes pugio*.

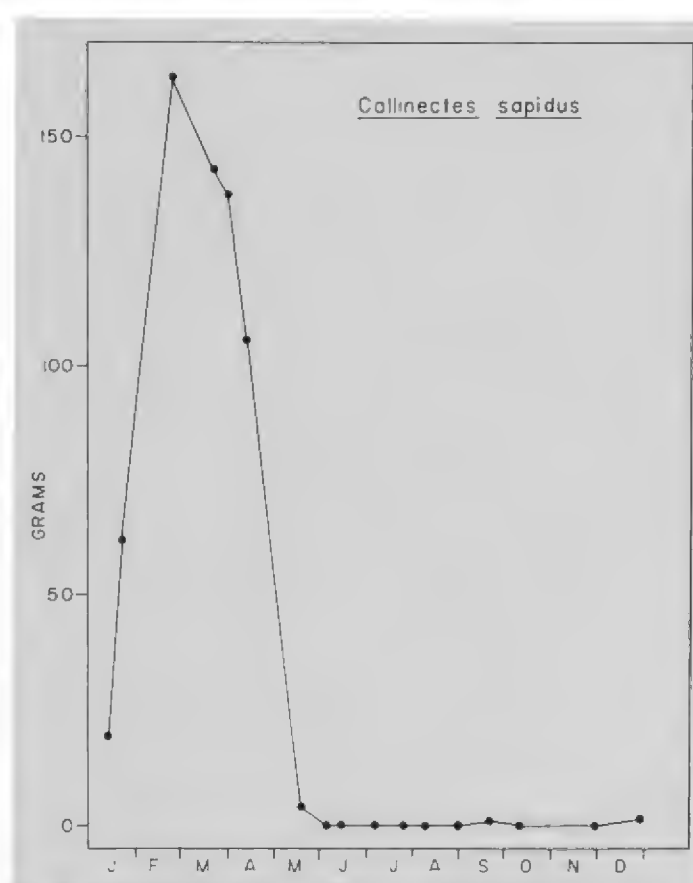


FIG. 6. Catch of blue crabs, *Callinectes sapidus*.

ing the hottest periods in June and July (Fig. 3) in contrast with most other species.

Lucania parva was widespread in the samples, but became abundant in July and August when other species were disappearing (Fig. 3).

Large schools of mullet, *Mugil cephalus*, occurred next to spoil banks, but did not inhabit the grassy areas in numbers until late summer and fall. Juveniles were taken only once (January 22). Adults were wary and difficult to catch even if caught in the trap.

Silversides, *Menidia beryllina*, were sporadic in occurrence until June. A sharp population increase occurred in late September and early October, after which they became scarce.

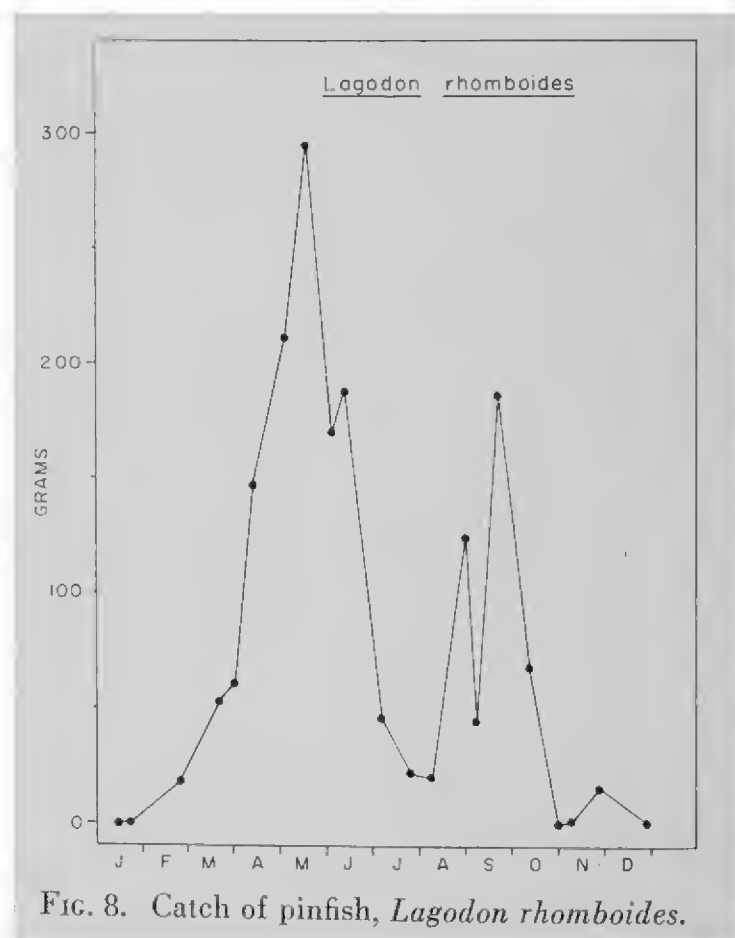
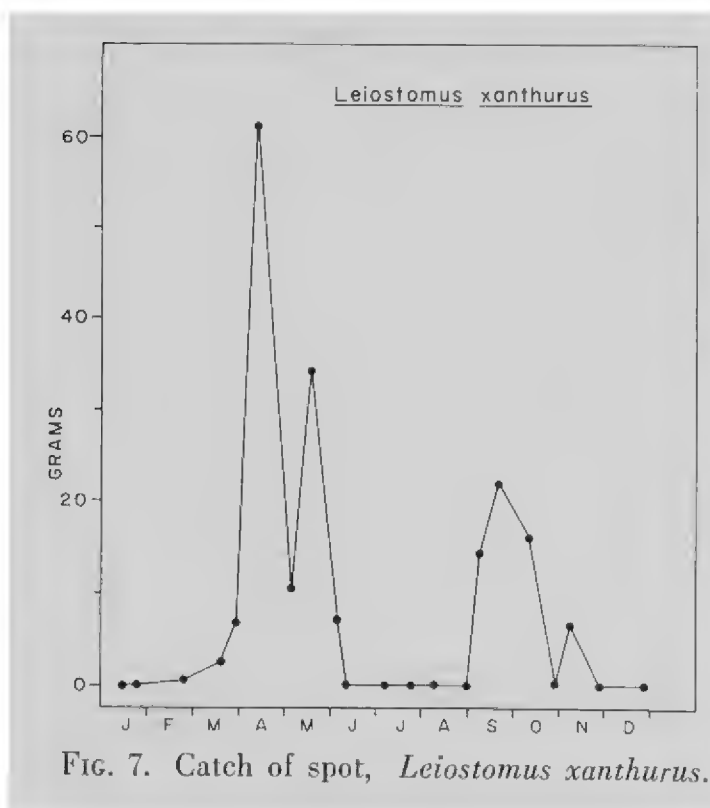
A mojarra, *Gerres cinereus*, was apparently another species characteristic of the community. Young appeared in June and reached a small population peak in August and September. Tabb and Manning (1961) reported this to be the most abundant mojarra in Florida Bay, which has grass flats.

Two population peaks of spot, *Leiostomus xanthurus*, occurred, one in spring and a smaller one in fall, with summer and winter absences in between (Fig. 7). Very small juveniles (20–30 mm) were taken only in spring.

A goby, *Gobiosoma robustum*, is another "indicator" species of grass flats (Springer and McErlean, 1961). It was taken in largest quantities in winter months, but since gobies are secretive, they may have been missed at other times.

A few other species were taken less commonly. These include *Anchoa hepsetus*, *Strongylura marina*, *Syngnathus scovelli*, *Hippocampus zosterae*, *Orthopristis chrysotus*, *Archosargus probatocephalus*, *Gobionellus boleosoma*, *Sciaenops ocellata*, *Bairdiella chrysura*, and *Paralichthys lethostigmus* of the fishes.

Several other invertebrates were inadequately sampled, even though occasionally taken in the trap. One of these was *Callinectes danaë*, which appeared in April after



Sargassum drifts with the crabs were brought into the bays. Many small forms are probably important community members much as *Crepidula*, *Cerithium*, *Bittium*, *Nassarius*, and caridean shrimp. Scallops, *Aquiptecten irradians*, were widely scattered in Redfish Bay entering the catches only in late spring. In early July numerous dead scallops were found, some with attached meats. A few other species were seen less often, such as *Anadara transversa*, *Crassostrea virginica*, *Brachidontes exustus*, and *Cliona viridis*. Members of the infauna such as *Lucina* sp. and *Chione cancellata* were encountered regularly.

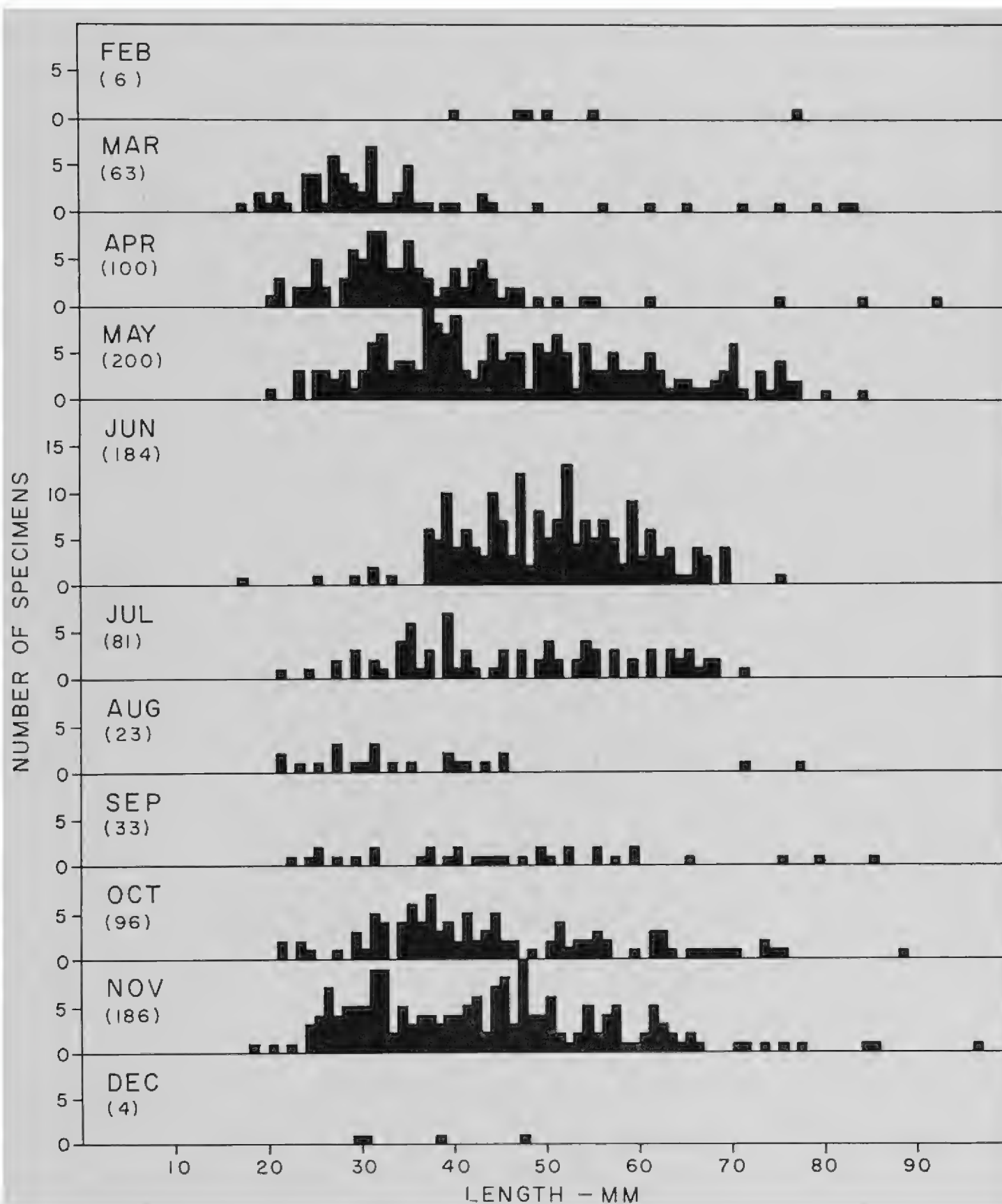
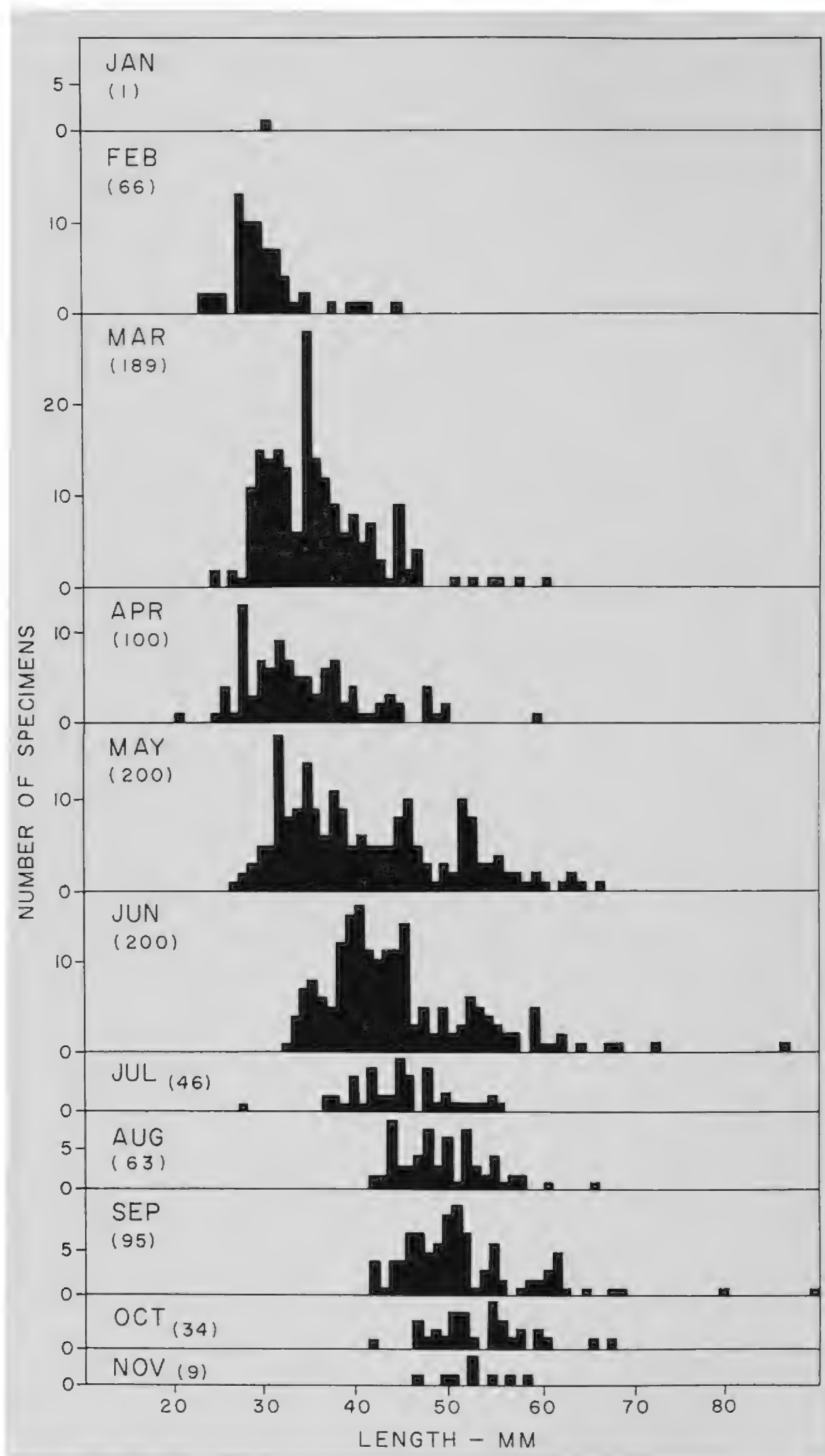


FIG. 9. Length frequencies by month for *Penaeus duorarum*.

FIG. 10. Length frequencies by month for *Lagodon rhomboides*.

Discussion

Animal populations in Redfish Bay increased and decreased rapidly. Only *Gobiosoma robustum* and *Lucania parva* sustained numbers over 50% of maximum level for two months, while most species lasted one month or less. The typical pattern was a large spring peak, a mid-summer absence, and a smaller fall peak. Not all species followed this pattern, however.

The general trend of total biomass correlates well with amount of water in the bay (Fig. 2). During winter sea level was low, food and cover were scarce, and temperatures were extreme. During spring as the bay got deeper and more food was available, populations increased. By mid-summer populations decreased as the bay lost its water and other factors became extreme, but the trend was reversed again in fall.

Hellier (1962), Odum and Wilson (1962), and especially Odum (1963) for Redfish Bay show that peaks of total biomass and primary production in Texas Bays occur in June and July. In our studies factors connected with the extreme summer environment have apparently prevented full utilization of Redfish Bay by the animals studied. Metabolism studies by Odum (1963) show that production is high in July and August in other years. Consideration of these data indicates that although adequate primary production is occurring, other environmental conditions are limiting. Two exceptional species, *Neopanope texana* and *Lucania parva*, overcame this and thrived in very hot waters.

THE GRASS ASSOCIATION

The data suggest that the grass community is as distinctive as any existing on the Texas coast. The most characteristic members of the Redfish Bay community were *Lucania parva*, *Gerres cinereus*, *Lagodon rhomboides*, *Gobiosoma robustum*, *Penaeus duorarum*, *Neopanope texana* and *Palaemonetes pugio*.

Perhaps the most diagnostic character of the community, however, was the complete absence of croaker, *Micropogon undulatus*. This was unexpected in view of the abundance of croakers in other Texas bays (Gunter, 1945, and others). Redfish Bay seems similar to bays on the west coast of Florida where croakers are rare (Reid, 1954; Springer and Woodburn, 1960; Tabb and Manning, 1961; and others). In these areas communities of marine spermatophytes predominate as in Redfish Bay. *P. duorarum* is the dominant penaeid on the Florida west coast (Springer and Bullis, 1954), and many species are common to the two areas; more than seem to be common to Redfish Bay and adjacent Texas Bays.

Acknowledgments

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TABLE 1

Most abundant animals taken in quadrat. First figure is average per month in gms/m²; second figure (in parentheses) is the average number taken per sample.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
<i>Lucania parva</i>	0.008 (4)	0.007 (3)	0.004 (1)	0.017 (4)	0.008 (4)	0.004 (2)	0.1 (39)	0.24 (160)	0.1 (68)	0.12 (83)	0.283 (183)	0.2 (131)
<i>Cyprinodon variegatus</i>	.....	.....	.....	.....	.....	.....	.....	X (1)	X (1)	X (1)	0.18 (11)	.....
<i>Menidia beryllina</i>	.....	.....	0.023 (1)	0.008 (12)	0.002 (3)	0.18 (30)	0.05 (11)	0.07 (8)	0.8 (87)	0.9 (105)	.....	0.13 (4)
<i>Gerres cinereus</i>	.....	.....	.....	.....	.....	0.008 (10)	0.004 (4)	0.07 (23)	0.075 (10)	0.02 (6)	0.02 (8)	.....
<i>Leiostomus xanthurus</i>	.....	0.004 (5)	0.04 (23)	0.52 (96)	0.189 (15)	0.03 (2)	.....	.....	0.15 (4)	0.07 (2)	0.03 (1)	.....
<i>Lagodon rhomboides</i>	0.001 (1)	0.15 (66)	0.49 (95)	1.3 (295)	2.14 (252)	1.52 (94)	0.3 (23)	0.6 (32)	0.98 (47)	0.3 (17)	0.072 (5)	.....
<i>Gobiosoma robustum</i>	0.008 (3)	0.016 (2)	0.022 (6)	0.033 (1)	0.016 (4)	0.001 (1)	0.003 (15)	.....	.....	X (1)	0.006 (5)	0.04 (19)
Total fish ¹	0.02 (8)	0.32 (76)	0.58 (126)	1.89 (408)	2.36 (278)	1.58 (139)	0.45 (92)	0.98 (224)	2.10 (217)	1.40 (215)	0.59 (213)	0.40 (154)
<i>Penaeus duorarum</i>	.....	0.08 (6)	0.18 (32)	0.5 (208)	2.1 (234)	0.96 (92)	0.35 (41)	0.06 (12)	0.17 (17)	0.55 (53)	0.89 (93)	0.02 (4)
<i>Palaemonetes pugio</i>	0.034 (25)	1.8 (828)	0.75 (313)	0.63 (302)	0.031 (15)	0.001 (2)	0.08 (11)	0.001 (1)	0.004 (2)	.....	.....	0.20 (249)
<i>Alpheus heterochaelis</i>	0.010 (4)	0.06 (10)	0.006 (2)	.....	0.01 (1)	0.009 (1)	.....	.....	0.005 (1)	.....	0.03 (2)	.....
<i>Neopanope texana</i>	0.051 (7)	0.02 (2)	0.069 (17)	0.113 (25)	0.036 (6)	0.085 (16)	0.4 (75)	0.19 (31)	0.13 (13)	0.02 (4)	0.06 (21)	0.12 (12)
<i>Callinectes sapidus</i>	0.325 (26)	1.4 (59)	1.2 (45)	0.9 (43)	0.228 (21)	0.002 (1)	.....	.....	0.007 (1)	.....	.....	.....
Total invertebrates ²	0.73 (62)	3.36 (905)	2.20 (409)	2.14 (578)	2.40 (277)	1.06 (112)	0.83 (127)	0.45 (44)	0.32 (34)	0.57 (57)	0.99 (116)	0.34 (265)
TOTAL ^{1,2}	0.74 (70)	3.68 (981)	2.78 (535)	4.02 (986)	4.76 (555)	2.37 (251)	1.29 (219)	1.43 (268)	2.42 (251)	1.97 (272)	1.58 (329)	0.74 (419)

¹ Less *Mugil cephalus* and *Opsanus beta*.

² Less *Libinia dubia*.

³ X indicates weight of a single individual less than 0.1 g.

Productivity Measurements in Texas Turtle Grass and the Effects of Dredging an Intracoastal Channel

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Abstract

Measurements of benthic chlorophyll "A" and diurnal oxygen productivity were made in turtle grass beds containing *Thalassia testudinum* and *Diplanthera wrightii* in Redfish Bay, Texas, before and after the dredging of an intracoastal canal. Moderate values of photosynthesis 2 to 8 g O₂/m² per day were observed in the spring of 1959 following a period of shading by turbid dredge-waters, but exceptionally high values 12 to 38 g/m² per day were recorded the following spring in those areas not smothered with silt. Chlorophyll "A" in 1959 averaged 0.0338 g/m² but increased to 0.68 g/m² the following summer.

Introduction

The high productivity of turtle grass ecosystems in Texas, Florida, and Puerto Rico has already been established by previous measurements of diurnal properties. Oxygen production values, for example, have been found up to 40 g/m² per day (Odum, 1957; Odum and Hoskin, 1958; Odum, Burkholder, and Rivero, 1959; Odum and Wilson, 1962). Bottle studies compared with free water measurements (Odum and Hoskin, 1958) indicated the minor role of plankton production as compared with benthic production in these flats. High densities of juvenile animal populations in these shallow systems have been established in an annual study in Texas flats with the drop net by Hoes and Jones (1963), and by studies of Springer and Woodburn (1960). High values of Chlorophyll "A" in the benthic plants were given by Odum, McConnell, and Abbott (1958). These indices support the concept that is widely held in the Gulf Coastal region that the grassy shallows are food production nurseries, at least during the warmer seasons. Schultz (1961) discusses the distribution of juvenile fish and shrimp in the study area.

In 1959 an intracoastal channel 12 ft deep and 125 ft wide was dredged through Redfish Bay, Aransas Pass, Texas, an area of fertile grass previously studied as cited above. Data on this bay were obtained relative to the dredging operation by several persons. Kornicker, Oppenheimer, and Conover (1959) described some mud-balls resulting from the dredging. Hellier and Kornicker (1962) described the stations and the sedimentological effects in which there was heavy sediment accumulation associated with a spoil island extending about 0.2 mile. Ronald Schultz (personal communication) reported some variable animal collections from push net and shovel-sieve sampling at the same stations. *Lucina pectinata* and *Chione cancellata* were predominant. This report

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concerns two indices of productivity, diurnal oxygen curves and chlorophyll "A" during this period.

Area and Sequence of Events

Redfish Bay is pictured in the map in Fig. 1. Fig. 2 has aerial photographs of the study area facing east from the spoil bank along the transect line of 5 stations set up at about 0.25 mile intervals. Prior to dredging the water was deepest at station 1 where *Thalassia* beds were maximal (about 0.5 m at ordinary tide levels), shoaling gradually to 0.30 m at station 5 with increasing percentages of *Diplanthera*. Station distances given in Hellier and Kornicker (1962) were apparently too large.

Some measurements of productivity were made in similar grass in the area of Ransom Island south of the Port Aransas Causeway in 1957. The transect of station poles was set up north of the causeway in November 1958. The dredge began to affect the area in the last of February 1959 with clouds of drifting silt obscuring the grass on many days

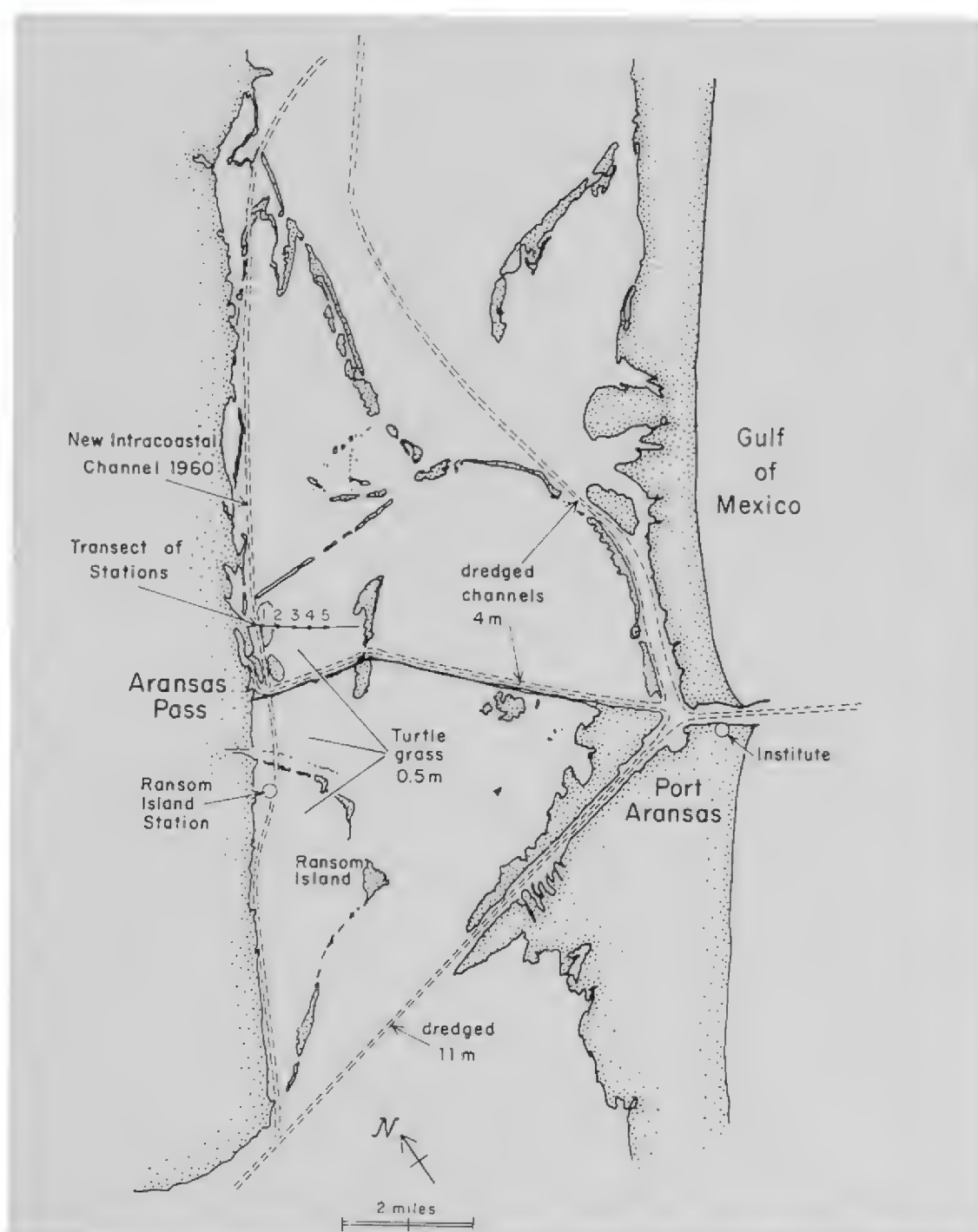


FIG. 1. Map of Redfish Bay near Aransas Pass, Texas, indicating the study area, the 5 stations, the intracoastal channel, and the Ransom Island Station.



FIG. 2A. Aerial photographs: above, March 21, 1961, with a view facing east across the new spoil island along the transect of 5 stations. Note the outline of the uncovered grass between stations 2 and 3. Below, new channel and spoil islands.

around March 1, 1959. Then dredging was stopped when rock was reached so that by March 13 the dredge had been removed and the water again was clear. No spoil island had been deposited at this time in the transect area. Final dredging began again in November 1959 with the deposition of the spoil island and silt on top of the grass as far as station 2 as seen in Fig. 2. Thereafter measurements of productivity were made in the vicinity of station 3, which received a few centimeters of silt only.

Methods, Replications Within the Bay System

Measurements of productivity with the diurnal method were made as described in detail in a previous paper (Odum and Hoskin, 1958). Fig. 3 is a representative diurnal graph with computations as used for estimating gross production and total community respiration. Following the earlier studies on this and other similar shallow bays in which the aeration coefficient on a volume basis was observed to be relatively conservative



FIG. 2B. Aerial view of turtle grass beds (dark areas) prior to dredging of the intracoastal channel. Photograph was taken March 20, 1950 by the U.S. Production and Marketing Administration (DIX-6G-49).

(Odum and Wilson, 1962), a constant reaeration constant (k) was used in this paper as $1 \text{ g O}_2/\text{m}^3$ per hr for 100% deficit gradient across the water-air interface.

In the preceding paper some duplicate stations were studied in Redfish Bay along with some measurements within a fiber glass enclosure. Similarly, in the data taken in 1961, 2 to 5 duplicate stations were measured in order to indicate homogeneity and heterogeneity of the circulating waters. Some representative curves reproduced in Fig. 4 indicated a general similarity in metabolic patterns at the main stations in the waters over the grass flats of Redfish Bay. Each curve was based on sample pairs taken at each time of measurement. The moving water averaged the production over sizeable areas. Thus, samples taken at different stations as shown in Fig. 4 were sub-samples. When the productivity for each curve was computed separately, station differences were greater (Fig. 5) because the station depths were different. The general similarity of the graphs in Fig. 4 may justify computations which were made when data from only one of these stations was obtained.

The approximation of constant daytime and nighttime respiration often used in productivity studies for lack of better information was continued in this paper throughout for purposes of uniformity although it was recognized that this approximation may be far from accurate. In considering the ratio of P (gross photosynthesis) to R (total system

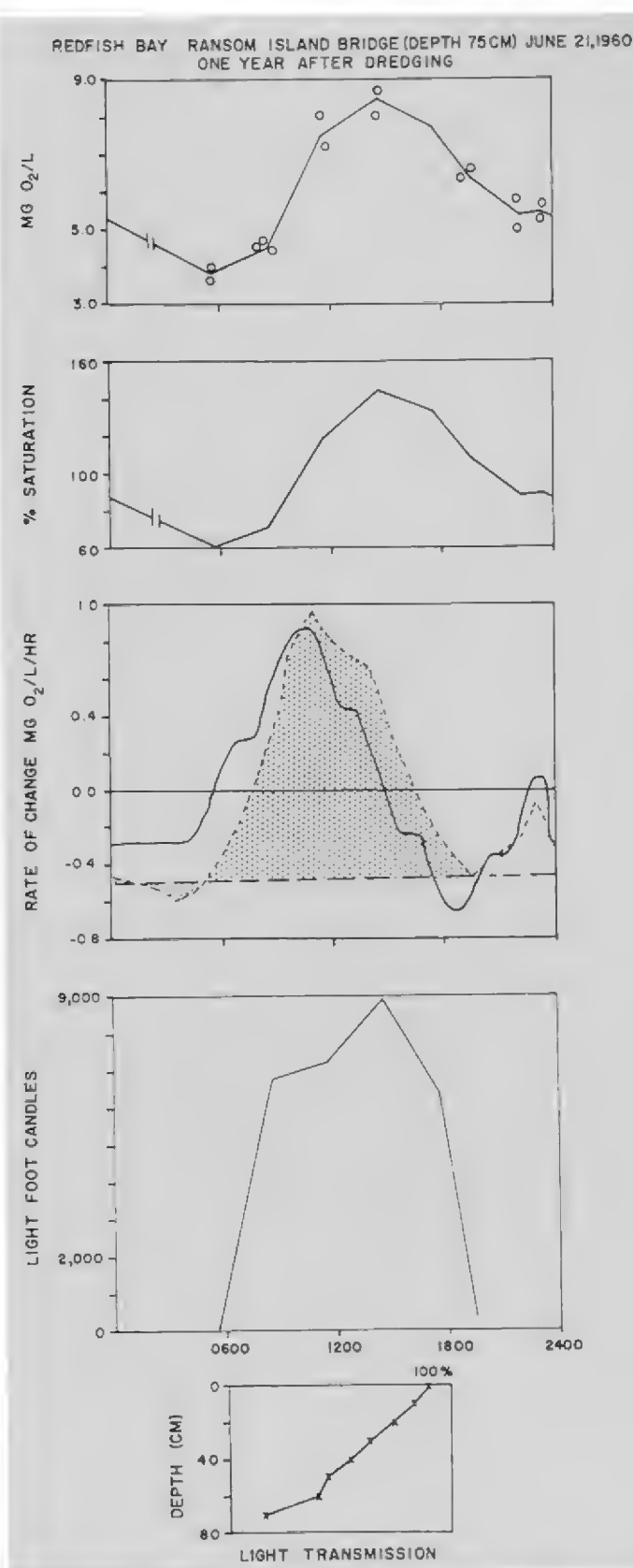


FIG. 3. Diurnal curve from a station near Ransom Island, June 21, 1960, the summer following the dredging. Vertical transmission of white light with a selenium photometer and frosted glass is provided in the lower graph. Summer graphs like this one show a post-sunset bulge and artifact due to the strong evening sea breeze providing increased aeration not allowed for in the diffusion correction.

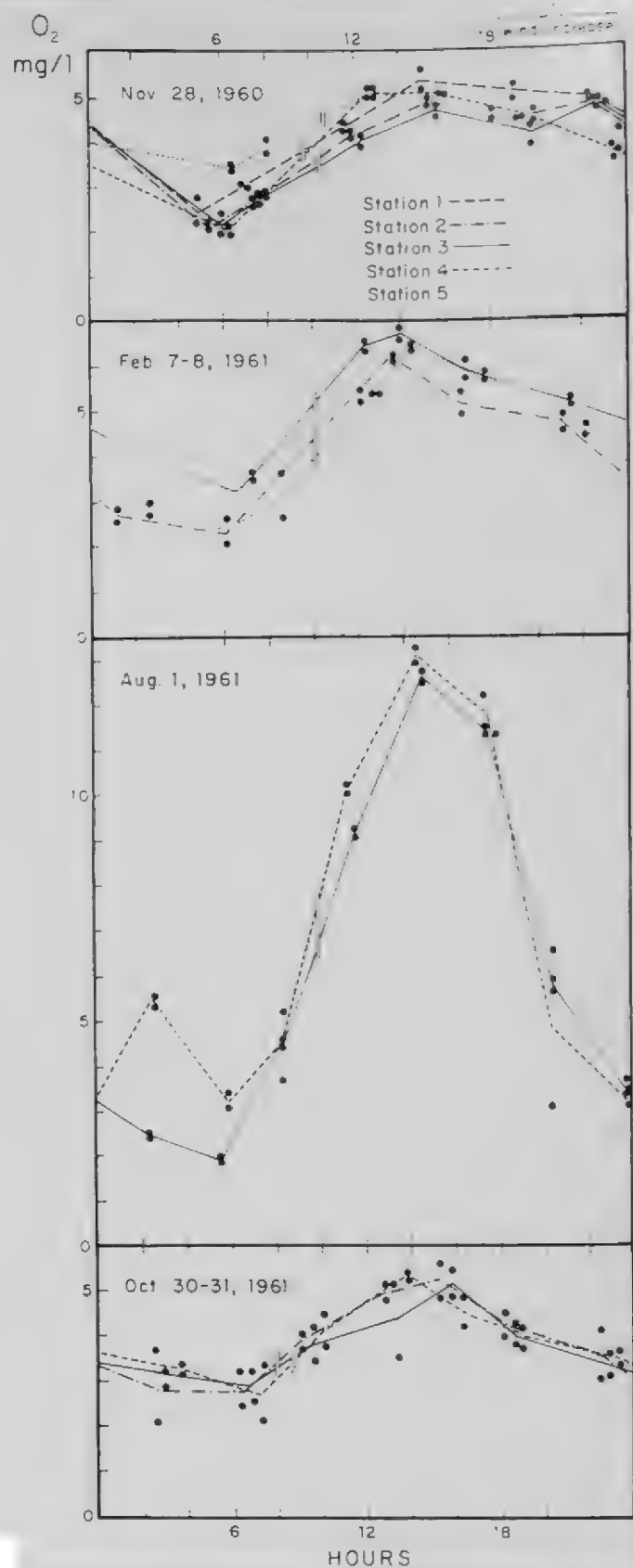


FIG. 4. Oxygen curves taken at more than one station at the same time. Metabolic figures based on these curves were computed separately and included as points in Fig. 6.

respiration) any error in drawing the base line for daytime respiration affects both P and R.

In Fig. 6 is reported one graph in which the diurnal oxygen and diurnal carbon metabolic rates are both plotted. The carbon-dioxide metabolism was computed with the pH-CO₂ titration method (Beyers and Odum, 1959). pH was taken with a Beckman

Model W industrial meter operating in the field from a generator. The quotient of carbon to oxygen metabolism was 1.3 for gross photosynthesis and 1.25 for respiration. Since the carbon-metabolism data do not involve a diffusion correction and since the quotients are not greatly off from the range expected in ordinary metabolism of single organisms in aerobic processes, some additional confidence may be derived concerning the interpretation of the figures for P and R. The kind of abnormal respiratory quotients found in some polluted systems, anaerobic marine bays, and bottle studies, were apparently not involved in the aerobic grass flats. Three other examples were studied in grass flats of the Lower Laguna Madre (Table 2).

Chlorophyll "A" was measured in the benthic plants as described in Odum, McConnell, and Abbott (1958). Conover's stove pipe sampling procedure was used to collect the plants which were washed, ground, aliquoted, and extracted in acetone. Whereas the freewater diurnal values represented larger expanses of the bay averaged, chlorophyll measurements of benthic plants served as an index of localized fertility.

Results

Fig. 3 is a typical diurnal record of oxygen with graphic computations for estimating gross photosynthesis and total community respiration. Fig. 6 is a record of the diurnal curve measurements in Redfish Bay grass flats from 1957 through 1961, each pair of points representing one diurnal record like that in Fig. 3. A record of salinities, the times of dredging, and other events, are also noted. The strongly seasonal pulse of productivity like that previously found in the Laguna Madre in a 4 year series is recognizable with winter minimum.

Chlorophyll "A" contents of the benthic plants in 1959 and 1960 are reported in Table 1 with very large differences observed. The relatively sparse grass during 1959 was followed by thick growths in 1960 as indicated in the chlorophyll "A" figures. The dry weights of benthic plants per m² for July 26 samples (stations 3, 4, and 5) were 470, 322, 464, 427; 634, 409, 418, 516; 232, 192, 181, 217. The weights per area were less than turtle grass weights in Puerto Rico measured by Burkholder (1959) reflecting in part the smaller proportionate weight of the rhizome systems in the Texas beds.

The Redfish Bay beds during the sparse condition of summer 1959 were apparently similar in density to those of Boca Ciega Bay, as reported by Pomeroy (1960) with 0.054 g/m² of benthic chlorophyll and 81 g/m² dry plant matter.

The productivity and chlorophyll "A" data indicate diminished fertility during the year 1959 when there was some disturbance and shading in the spring. Values of photosynthesis and chlorophyll were less than in previous years. In contrast, 1960, the year immediately after dredging, had unusually heavy growths and higher values of photosynthesis and chlorophyll than observed previously, except in stations 1 and 2 where the benthic communities had been smothered with soft silt. On February 7, 1961, after the annual winter decline, chlorophyll "A" values were as high as those in the summer of the dredging. Winter values in winter of 1958 before dredging ranged 0.04–0.48 g/m². Station 2 was examined further during the fall of 1962 and still had no growths other than microscopic algae and a few diminutive blades of *Ruppia*. There was an algal crust but the silt below was little consolidated.

In previous studies an excess of respiration over photosynthesis was noted when salinity was falling in Texas bays associated with river-borne organic matter, but photo-

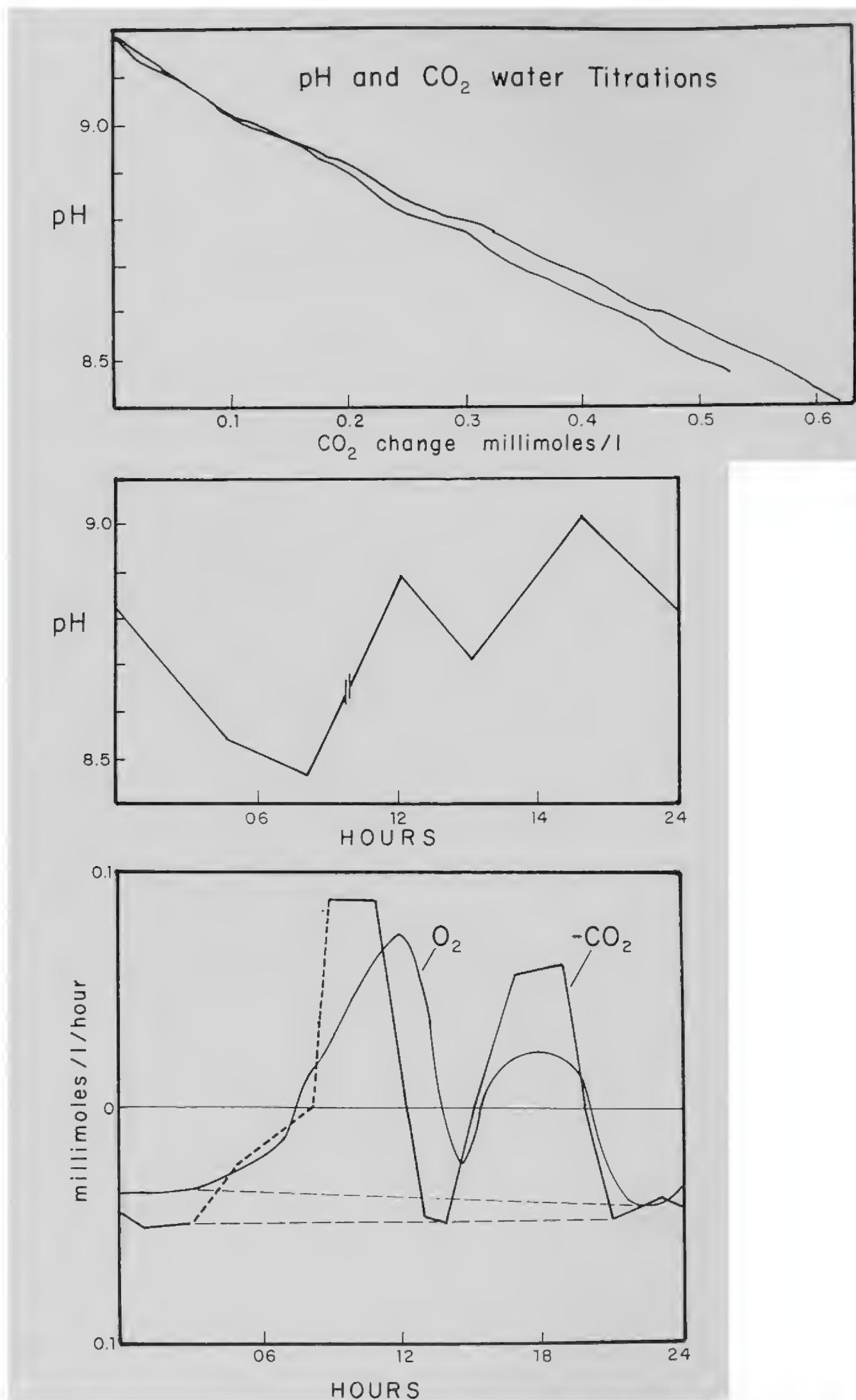


FIG. 5. Diurnal oxygen and pH curves for Redfish Bay, station 2, Aug. 15-16, 1961. The rate of change graphs for both oxygen and carbon are plotted together below on a millimole per hour basis. The carbon curve is reversed with increasing values plotted downward.

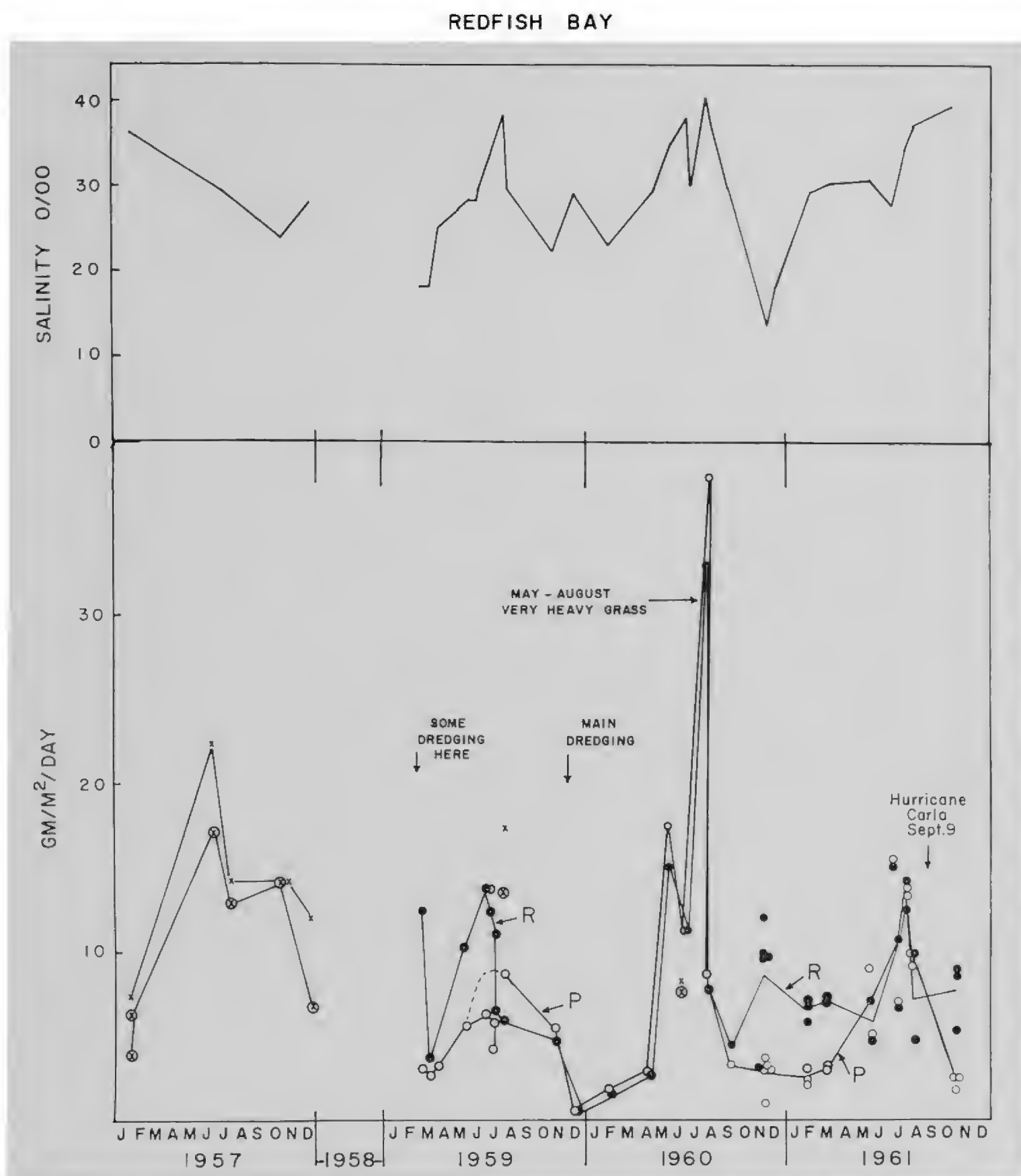


FIG. 6. Record of salinity, gross photosynthesis, and total respiration 1957-1961. Data represented by crosses (x) were taken near Ransom Island (Fig. 1) whereas the other data were taken between stations 2 and 3 in the transect.

synthesis and respiration in high salinity waters of Redfish Bay were usually similar. The 1959 data were distinctive with a greater imbalance with excess respiration over photosynthesis. Much higher R than P was found in the fall of 1960 at a time when excessive benthic growths of the previous year were decaying and salinities were diminishing.

Diurnal productivity data from the grass beds near Port Isabel, Texas are included in Table 2. The values were comparable with those in the Redfish Bay area.

TABLE 1

Chlorophyll "A" in benthic plants along the Redfish Bay transect in 1959 and 1960. Data in g/m²

Station	Distance from new channel	Summer 1959	Summer 1960	Winter|| 1961
1	0	0.0078* 0.0113* 0.0180* 0.0086* 0.029* 0.052* 0.0015* 0.115* 0.041†	Station now out of water as spoil island.	-----
2	0.25 mile east	0.0208‡ 0.0106‡ 0.0074‡ 0.0052‡ 0.0105‡ 0.0110†	Beds covered with 30 cm of soft silt; no plants.	-----
3	0.5 mile east	0.079§ 0.042§ 0.087§ 0.022§ 0.062†	1.14¶ 1.21¶ 1.32¶ 1.46¶	0.021 0.019 0.153 0.103 0.130 0.012 0.055 0.133
4	0.75 mile east	0.087§ 0.033§ 0.011§ 0.048†	0.26¶ 0.42¶ 0.49¶ 0.47¶	-----
5	1.0 mile east	0.050§ 0.022§ 0.0195†	0.20¶ 0.26¶ 0.28¶	-----
Mean		0.03379	0.6827	-----

* May 30, 1959.
† July 15, 1959.
‡ April 27, 1959.
§ June 30, 1959.
¶ July 26, 1960.
|| Feb. 7, 1961.

TABLE 2

Metabolism of Turtle Grass Bay Areas in the Lower Laguna Madre at Port Isabel, Texas

	Depth m	Salinity ‰	T	Oxygen g/m ² /day		Carbon g/m ² /day		Quotient CO ₂ /O ₂	
				P	R	P	R	AQ	RQ
August 8-9, 1960	1.4	37	28-30	26.3	13.8	-----	-----	-----	-----
	1.4	37	28-30	30.0	19.7	-----	-----	-----	-----
	0.9	37	28-30	11.7	4.3	-----	-----	-----	-----
January 20-22, 1961	1.8	30	11-12	4.0	5.8	-----	-----	-----	-----
July 3-4, 1961									
Port Isabel	1.5	37	-----	10.8	8.3	3.6	3.0	0.9	1.0
Laguna Vista	1.0	40	-----	11.2	10.3	11.2	6.8	1.7	1.8
Queen Isabel Causeway	1.0	36	-----	7.4	9.6	6.7	7.4	2.4	1.5

Discussion

Data reported here indicate a marked seasonal cycle in productivity with considerable year to year variation possible. The values for the Redfish Bay Turtle Grass were not as high as some grass flat data in the lower Laguna Madre of Texas where higher values were recorded associated with clearer waters (Odum and Wilson, 1962).

The decreased productivity and imbalance of respiration over photosynthesis of the summer of 1959 may have been associated with the silts turned loose over the flats by the start of dredging that spring. Certainly, during the weeks of dredging nearby, light penetration was much reduced and the plant beds may have received a set-back at this time.

Whatever diminished productivity during that year was not permanent. Growths the following year were exceptional. The suggestion by Ingle (1952) that dredging may stimulate by adding nutrients may have merit.

Apparently, therefore, the channel dredging entirely removed from the available nursery grounds the 125 ft of channel and a quarter of a mile of beds under and adjacent to the spoil island, but did not permanently damage the productivity of the beds beyond. A geometric consideration may be important in comparing these results to those given by Ingle (1952) and Mackin (1962) for dredging in slightly deeper waters. Where the spoil from a channel of this dimension is discharged in only 0.5 m of water or less, it may shoal the water depth critically over a much wider zone than where the discharge is into a bay that is already 3 to 10 ft in depth.

In the fall and winter of 1960–1961, respiration remained higher than photosynthesis. Close similarity of P and R which was observed in Redfish Bay in 1957 and 1960 and in 4 years in the Laguna Madre was upset. The great mats of decaying grass observed in the fall of 1960 due to the exceptional growth that summer and the influx of low salinity river water may have raised respiration rates. P and R were again in balance during the growing season of 1961, but another excessive respiration period was found following Hurricane Carla, possibly reflecting the upset bottom conditions following an approximate 8 ft tide and storm waves over the flats. Photosynthesis Oct. 31, 6 weeks following the hurricane, was less than photosynthesis at this time in other years. Because the center of the storm went inland to the east, rains in the Redfish Bay area were not excessive and salinities in this bay did not fall excessively. Thomas, Moore, and Work (1960) found extensive windrows of turtle grass following a hurricane in the Miami area, but showed from weight calculations that the portions of the beds washed ashore were negligible.

The record of metabolism and chlorophyll "A" as reported over the period from 1957 through 1961 indicated some pattern of a regular seasonal pulse, but the changing patterns of precipitation, hurricanes, and man-made interferences such as dredging were apparently keeping the ecosystem metabolically upset so that the kind of steady state found in shallow aquarium ecosystem of benthic plant type (Beyers, 1963) did not become established. The imbalances of P and R were related to the type of disturbance such as organic storages and lags; bottom disturbances; organic river imports; and damage to plant beds.

Acknowledgments

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Amino Acids in Redfish Bay, Texas¹

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AND D. W. HOOD⁴

Abstract

Approximately 18 different amino acids in acid-hydrolyzates of dissolved organic matter in the sea water of Redfish Bay, Texas, have been identified by ion exchange chromatography. The organic matter was initially isolated from sea water by ferric hydroxide co-precipitation method. The amino acids identified are: glutamic acid, aspartic acid, glycine, serine, alanine, lysine, leucine, threonine, isoleucine, arginine, tyrosine and phenylalanine, proline, valine plus cystine, ornithine, β -alanine, histidine, methionine and methionine-sulfoxide. Although not strictly quantitative, the results indicate that higher concentrations of amino acids are dissolved in a fertile bay water than in open sea water.

Introduction

Because organic matter dissolved in sea water often occurs in concentrations of 1 mg/liter while there coexist about 35 g/liter of inorganic salts, it is not easy to isolate and concentrate sufficient quantities of the organic matter without destroying or altering it. Despite the experimental difficulties, progress has been made in the field of organic chemistry of the sea in recent years.

Vallentyne (1957) and Duursma (1960) compiled lists of various dissolved organic substances found in sea water. Jeffrey and Hood (1958) evaluated various methods for the isolation of organic matter in sea water. They found that co-precipitation of the organic matter with ferric hydroxide was an effective way to concentrate a part of the dissolved organic matter.

Recent experiments on the recovery of known amounts of C¹⁴-labeled amino acids in sea water by the ferric hydroxide co-precipitation method yielded a recovery range of a minimum of 30% for alanine and a maximum of 85% for lysine. A study of the recovery of peptides and proteins is under way at the Chemical Oceanography Laboratory of A. and M. College of Texas. Preliminary results indicate nearly quantitative yields.

By the use of the ferric hydroxide co-precipitation method, Tatsumoto et al. (1961) and Park et al. (1962) investigated the occurrence of amino acids in acid-hydrolyzates of the dissolved organic matter from open sea waters. They identified about 18 different amino acids by ion exchange chromatography developed by Moore, Spackman and Stein (1958).

Higher concentrations of dissolved organic matter have been reported in fertile bays than in the more open water by Collier (1958), Collier et al. (1953), Wangersky (1952), Wilson (1961) and others. A question can be raised whether the amino acids are more concentrated in such productive waters than open waters. Using the experimental pro-

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cedure followed previously (Park et al., 1962), a study was made of the occurrence of amino acids dissolved in the water of Redfish Bay near Port Aransas, Texas. This is a fertile inshore bay, dominated by turtle grass beds.

Methods

WATER SAMPLING

On 16 May 1960 approximately 170 liters of sea water were collected from Redfish Bay, at the same location occupied for studies of diurnal pH variation by Park, Hood and Odum (1958). Several milliliters of chloroform were immediately added to the water to reduce the metabolic activities of living organisms. At the station, the water was filtered through Curtin No. 7775 general laboratory type filter paper. The water was then immediately brought back to the laboratory in polyethylene containers, and was filtered once more through HA Millipore® filters.

CO-PRECIPITATION OF ORGANIC MATTER WITH FERRIC HYDROXIDE

The filtered sea water was placed in a polyvinyl chloride plastic tank. Under vigorous stirring, 50 ml of 2 M FeCl_3 solution were added to the sea water. After several minutes, 2 N NaOH solution was added to raise the pH of the sea water to 9.0–9.1. After the stirring was continued for 30 minutes, the precipitates were allowed to settle overnight. The precipitates were then drawn into a small container. Further removal of remaining sea water was achieved by centrifugation. The precipitates were then dissolved with a minimum amount of 1 N HCl solution.

SEPARATION OF PROTEINACEOUS FRACTION FROM THE CO-PRECIPITATED ORGANIC MATTER

The pH of the dissolved ferric hydroxide precipitates was adjusted to 1.0 by adding a slight amount of either HCl or NH_4OH . The resulting solution was then passed through Dowex-50 cation exchange resin column, H^+ form, $\times 8$, 200–400 mesh, 9×60 cm, at a flow rate of 1–2 ml/min, followed by 3 liters of 0.1 N HCl.

After the resin column had been washed with 3 liters of triple distilled water, the proteinaceous fraction of the organic matter was eluted with 8 liters of 2 N NH_4OH at a flow rate of 1–2 ml/min. The volume of the fraction was condensed to 500 ml at 60° C under low pressure.

The pH of the proteinaceous fraction was raised to 9.5 by adding NaOH. The solution was then passed through IRA-400 anion exchange resin column, OH^- form, 200–400 mesh, 7×60 cm, at a flow rate of 1 ml/min. The proteinaceous fraction retained on the resin column was eluted with 3 liters of 2 N HCl at a flow rate of 3 ml/min.

The effluent thus obtained was then condensed to 200 ml at 60° C under vacuum. The condensed solution was refluxed for 24 hours in 6 N HCl solution under atmospheric pressure. The acid-hydrolyzed proteinaceous fraction was dried by a combination of low temperature evaporation and freeze-drying.

AMINO ACID RESOLUTION BY ION EXCHANGE CHROMATOGRAPHY

An approximately 100-liter sea water equivalent of the amino acid sample was dissolved in 5 ml of 0.1 N HCl. An aliquot of 2 ml, equivalent to 40 liters of original sea

water, was loaded on a Amberite CG-120 cation exchange resin column which had been graded to size by hydraulic flow by the Hamilton's method (1958). The Na^+ form of the resin, prepared by washing with 2 N NaOH, was equilibrated with a 0.2 M sodium citrate buffer solution at a pH value of 3.25. A 150-cm column effective in the separation of neutral and acidic amino acids was used for chromatographic resolution.

The sample in the column was eluted with a 0.2 M sodium citrate buffer solution at a pH of 3.25 at 30° C until alanine emerged from the column. The volume of effluent required to reach this stage was approximately 300 ml. At this point, the pH of the column was changed to 4.25 by adding a 0.02 M sodium citrate buffer solution at 50° C. All the amino acids except the basic forms were eluted in an effluent of 640 ml.

In order to separate the basic amino acids, a second column, 50 cm, but of larger particle size and equilibrated with 0.38 M, pH 4.26, sodium citrate buffer solution, was used. After the emergence of 400 ml of effluent, the pH of the buffer solution was changed to 6.5 by adding 0.38 M sodium citrate. The elution was continued until 640 ml.

Two-ml fractions of all effluents were collected in test tubes, and a ninhydrin test was performed on all the fractions. The results of the ninhydrin test were expressed as leucine equivalent in micromoles.

Results and Discussion

Figures 1 and 2 show the ion exchange chromatograms of amino acids obtained from 15 liters of Redfish Bay water. Approximately 18 different amino acids were identified by comparing these with the chromatograms of known amino acids. The quantities of amino acids, without any correction for losses occurring during the assaying, are listed in Table 1. The reproducibility of the chromatographic separation gave an average precision of 5%.

TABLE 1

Amino acids found in the sea water of Redfish Bay, Texas by ferric hydroxide co-precipitation method

Amino acids	mg/m ³	μmole/m ³
Glutamic acid	5.5	38
Aspartic acid	5.4	41
Glycine	4.9	65
Serine	3.0	29
Alanine	2.2	25
Lysine	2.1	15
Leucine	1.9	15
Threonine	1.7	15
Isoleucine	1.3	10
Arginine	1.3	7
*Tyrosine and phenylalanine	(1.3)	(7)
Proline	1.0	9
*Valine plus cystine	(1.0)	(9)
Ornithine	0.9	7
Cysteic acid	0.8	5
β-alanine	0.6	7
Histidine	0.4	3
Methionine	0.3	2
Methionine-sulfoxide	0.2	1
Other ninhydrin-positive compounds	(3.0)	(20)
Total	(39)	(330)

* The peaks corresponding to these amino acids were poorly resolved on the ion exchange chromatogram. Numerical values in parentheses were estimated.

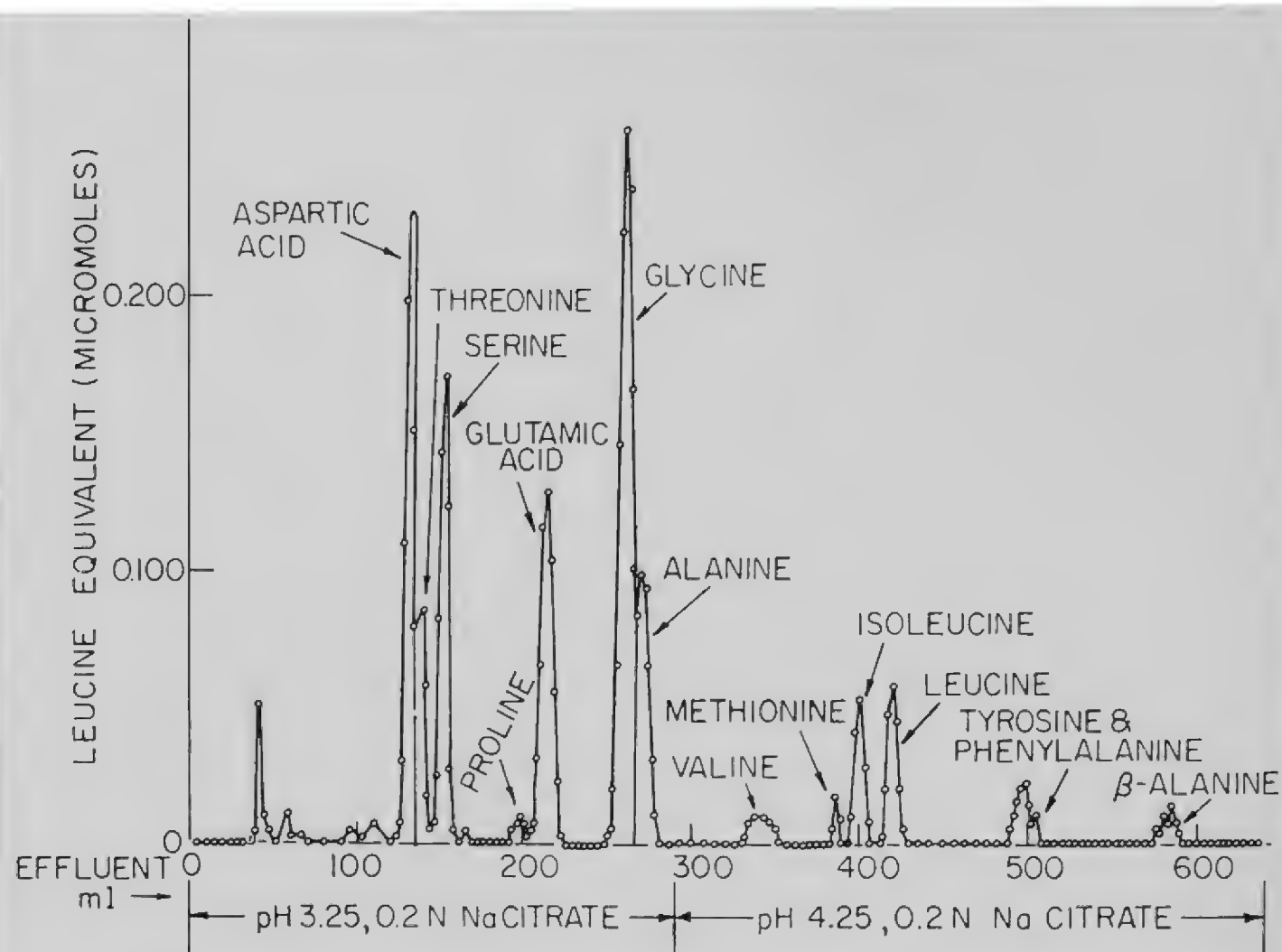


FIG. 1. Ion exchange chromatogram of acidic and neutral amino acids. Sample: 15 liters of sea water from Redfish Bay, Texas.

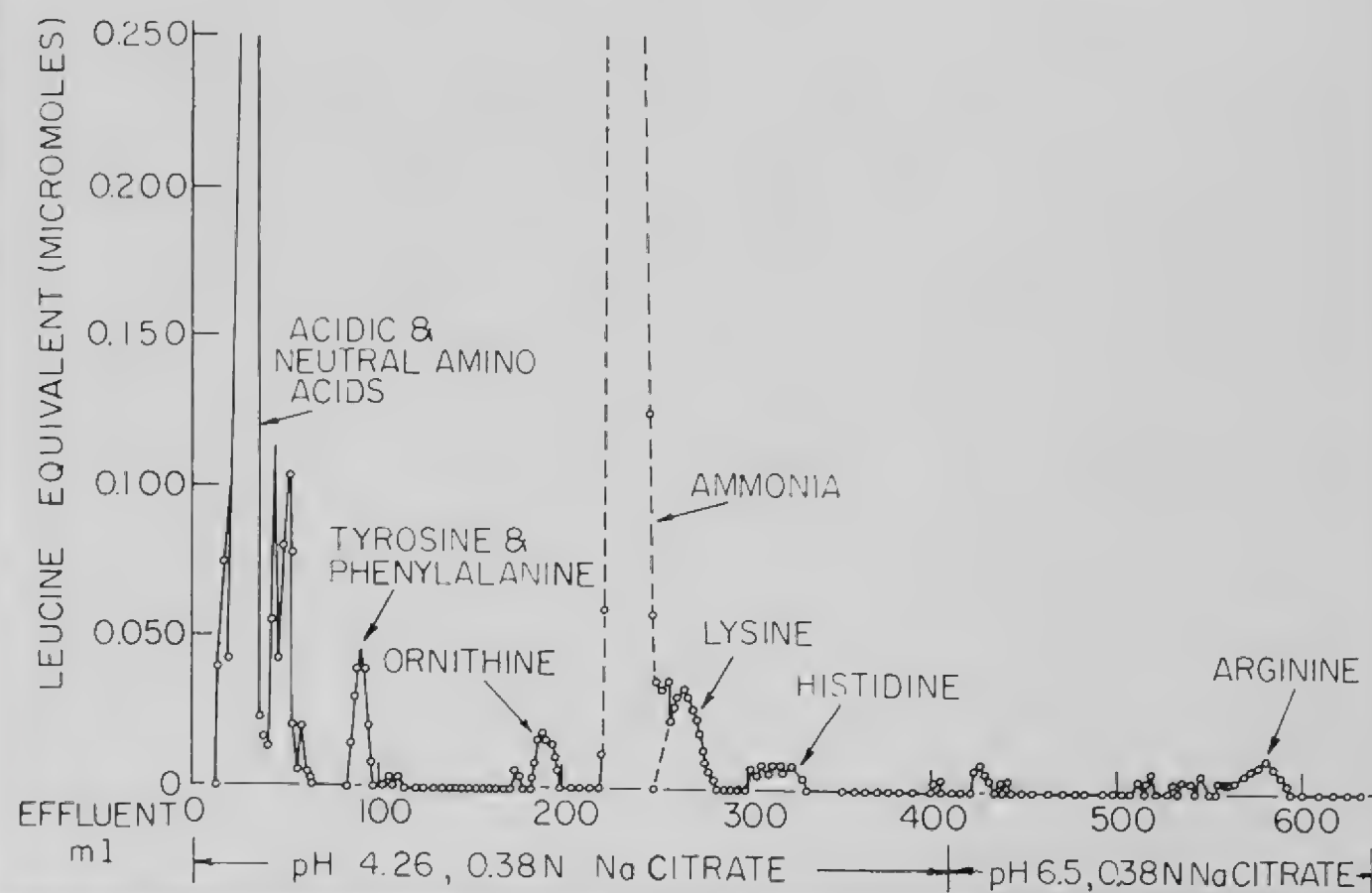


FIG. 2. Ion exchange chromatogram of basic amino acids. Sample: 15 liters of sea water from Redfish Bay, Texas.

A chromatographic peak which possibly represented β -alanine was observed from the bay sample, but not from open waters (Park et al., 1962). It may be a degradation product of pantothenic acid.

Since our data are not corrected for the losses of organic matter which may have occurred during the isolation and assaying, reliable quantitative values have not been obtained. Further work is necessary on the development of quantitative techniques. However, we find about 0.3 μ M of amino acids in the bay water, which are several times greater than the off-shore water (Park et al., 1962). Our findings, therefore, correlate favorably with the high primary productivity of the bay (Odum and Hoskin, 1958; Park, Hood and Odum, 1958), and the high organic carbon content, 6 mg/liter, of the bay water (Wilson, 1961).

This paper merely indicates the existence of some of the common amino acids in the fertile Redfish Bay water. We hope it will help to reemphasize the importance of dissolved organic molecules on the ecology and biochemistry of aquatic environments, which has been stressed by Collier (1953, 1958), Vallentyne (1957) and others.

Acknowledgments

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Organic Carbon Levels in Some Aquatic Ecosystems¹

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Abstract

An infrared gasometric method was used to investigate the organic carbon levels in the coastal waters of Texas, in contributing rivers, and in some other selected systems. The highest concentration of organic carbon found was over 100 mg/liter from samples taken from a salt pool in Puerto Rico. The lowest concentration was zero mg carbon/liter in two springs located in Texas limestone formations. Rivers fed by the springs increased in organic carbon concentration as they flowed toward the coast to 20 mg carbon/liter. In the Texas marine bays concentrations of organic carbon were 5 to 10 times higher than concentrations in the Gulf of Mexico (about 2 mg carbon/liter).

Introduction

Because of the difficulties with analytical methods for small concentrations of organic matter in waters where salt concentrations are high, reliable data on the levels of organic matter in marine waters are scarce and information for computing organic budgets in aquatic ecosystems have not been available. With large volumes of water involved, large amounts are involved and accurate determinations of the dilute concentrations are essential. In this contribution data on concentrations are reported for aquatic ecosystems of the Texas coast and elsewhere. Experimental studies on rates of change of organic matter in bottles, reefs, and cultures as verified by this direct method are reported elsewhere (Wilson, 1963).

Methods

INFRARED METHOD FOR DETERMINING ORGANIC CARBON CONTENT OF SEA WATER

The infrared (I-R) method used to determine the organic carbon content of sea water samples was previously described (Wilson, 1961). Since that time, the apparatus and procedure have been improved but the principle of operation is unchanged.

The I-R method consists of: (1) removing all inorganic carbonates from a sample of water; (2) oxidizing the organic carbon in the sample to carbon dioxide; and (3) measuring the carbon dioxide with an infrared analyzer.

Inorganic carbon dioxide was removed by acidifying the sample and passing carbon dioxide-free air over it while the sample was rapidly stirred. Oxidation was accomplished by heating the sample in a closed container with potassium persulfate. The carbon dioxide resulting from the oxidation of organic matter was measured with an infrared analyzer.

A diagram showing the various components of the apparatus used is presented in Fig. 1.

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Components of the System. Infrared carbon dioxide analyzer (Fig. 1): The instrument used which had sufficient sensitivity for measuring organic matter was a Beckman Liston Becker Infrared CO₂ Analyzer (model 15 A) with a 10 in. sample cell.

Pump (Fig. 1): A stainless steel Dyna-Vac pump (Cole-Parmer) with an output of 430 cubic inches per min was used to circulate and mix the gas inside the closed system. A valve on the pump permitted direct regulation of the gas flow without damaging the pump. The pump maintained a sufficiently high rate of flow to flush the system of carbon dioxide but not high enough to cool the thermostated carbon dioxide analyzer.

Corrosion of the stainless steel was reduced by installing the pump near the input-side of the combustion unit. Even with this precaution, corrosion remained a problem, and the inside of the pump was lightly coated with a low-vapor-pressure, carbon-free, grease to further avoid corrosion.

Tube containing potassium hydroxide (Fig. 1): The tube held approximately 200 gm of potassium hydroxide or sodium hydroxide, and constant refilling was unnecessary. A plug of glass wool was placed in the outlet of the tube to prevent potassium hydroxide dust from passing into the rest of the system where it could adsorb the carbon dioxide produced by oxidation of the organic matter.

Oxidation unit (Fig. 1): The glass combustion flask was made from a 500 ml heavy-walled Erlenmeyer flask which a glass blower had modified by the addition of two heavy-walled tubes.

Vacuum connectors (Central Scientific Company) were used to provide seals between the glass and the metal valves. Another set of vacuum connectors sealed the entire combustion unit to the rest of the system.

To eliminate damage to the valves from soldering or brazing them, the valves and connectors were screwed together. A piece of brass tubing, fastened to one end of the valve, joined the combustion unit to the rest of the system.

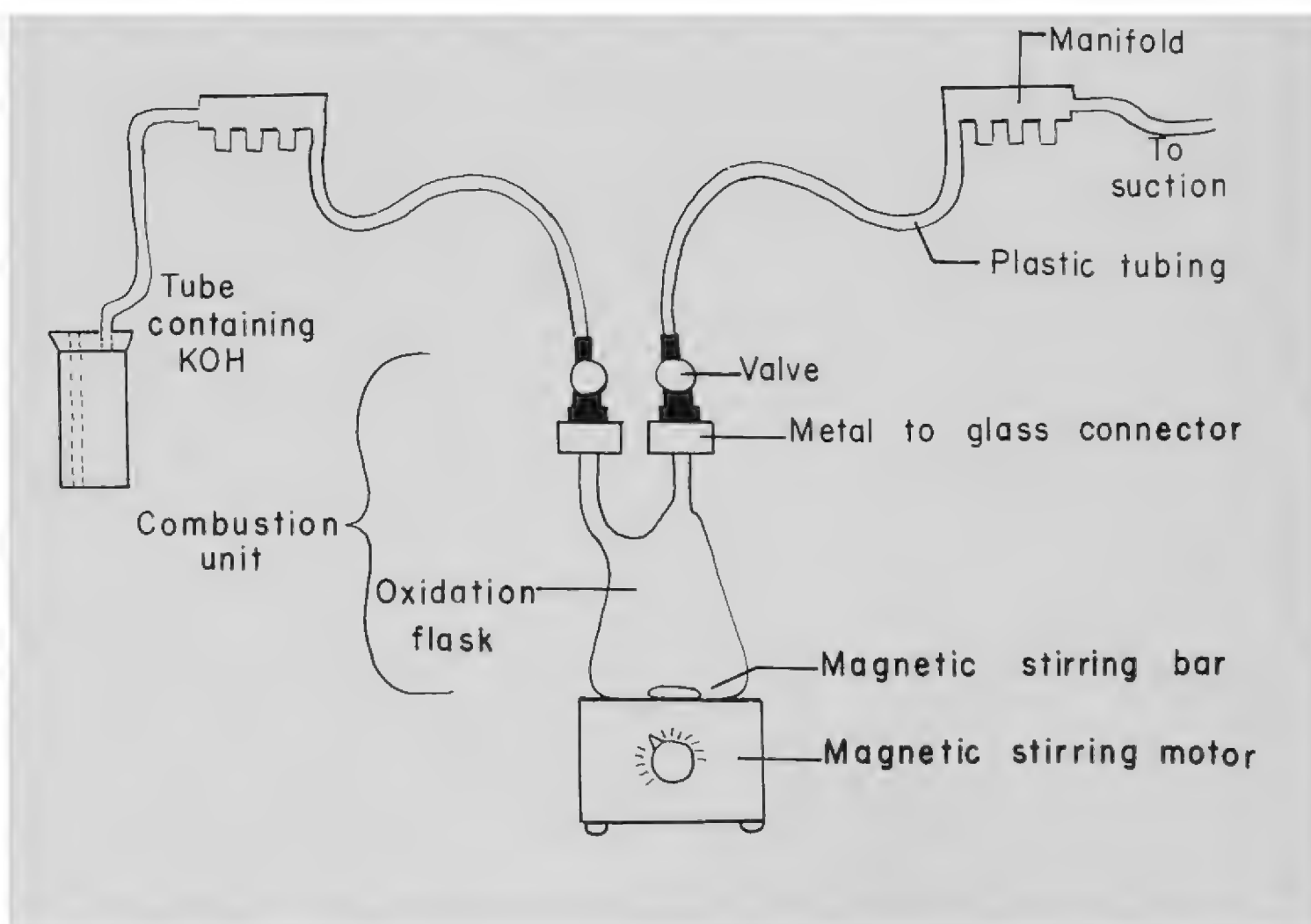
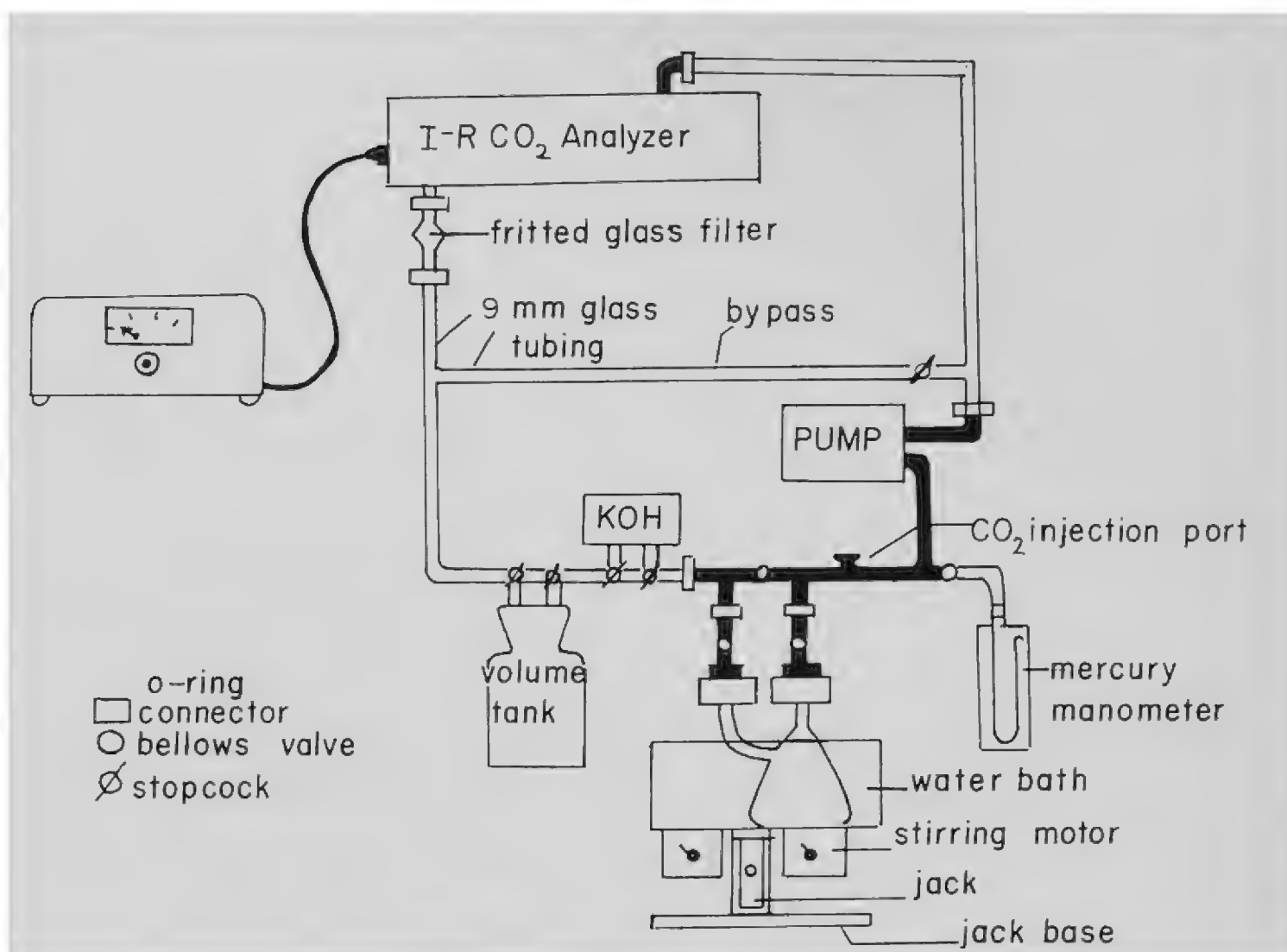
Water bath (Fig. 1): A temperature-regulated water bath was used to maintain the temperature of the water sample in the combustion unit at $20 \pm 1^\circ \text{C}$ while the carbon dioxide was measured.

The water bath was comprised of a glass tank with a cooling coil, a heater, and a thermostat. The tank was mounted on a wooden platform with a standard magnetic stirring device attached beneath it. To facilitate connecting and disconnecting the combustion unit, and to permit exact height adjustment of the water bath, the platform was mounted on a scissors jack.

Manometer (Fig. 1): A simple mercury manometer, with a valve between it and the system, was used for testing the pressure of the system after the analysis had been completed. The manometer consisted of a U-shaped glass tube open at both ends and half-filled with mercury. A short, heavy-walled plastic tube connected the manometer with the valve.

Problems Involved in Using the I-R Method. Two problems were encountered in using the equipment for the I-R method: gas leakage and corrosion. Leaks were eliminated by using fittings (Swagelok Company) for metal-to-metal connections; by using powdered teflon dispersed in water as a lubricant and sealer for all threads; by using metal-to-glass and glass-to-glass fitting (Cenco Company); and by using bellows valves on the combustion units.

Corrosion was not entirely eliminated as chlorine produced from the chloride in sea



water during the oxidation of the samples eventually corroded the best stainless steel and monel metal. The resulting rust clogged the valves and necessitated frequent cleaning of the I-R analyzer. If the rust was not eliminated, condensed water in the system mixed with it, producing a thick, dark brown, acidic fluid which invalidated the results of the analysis if it entered the sample cell.

Attempts failed to develop glass or plastic apparatus which would not corrode since feasible glass valves were not available and the plastics tried were permeable to carbon dioxide.

To minimize the problem, brass tubing and valves were used where necessary, also glass tubing and stopcocks where possible. Although brass corrodes, the corrosion by-products seemed to form a protective coat over the brass, reducing further corrosion.

Measures Taken to Prolong the Use of the Components. (1). The system was thoroughly flushed with dry air to reduce corrosion when the apparatus was not in use.

(2). The glass combustion flasks were annealed every 6 months to a year (depending on use) to reduce the strain on the glass from repeated heating and cooling.

(3). Since the I-R analyzer is sensitive to vibration, it was insulated as much as possible against vibrations.

(4). The sample tube gradually became contaminated by dirt and film causing a zero drift. The drift was corrected with the zero adjustment on the analyzer; and the tube was occasionally cleaned and once replated with gold. To reduce the necessity of frequent cleaning and replating, a bypass tube around the analyzer was used to prevent gas flow into the sample tube except just before the carbon dioxide was to be measured.

Apparatus Used for Serial Samples. The apparatus shown in the lower half of Fig. 1 was used for simultaneously removing inorganic carbon dioxide from several combustion units when serial samples were being analyzed. With this apparatus, the infrared analyzer could be used exclusively for measuring the carbon dioxide samples, while the inorganic carbon removal equipment provided a steady supply of samples to be analyzed. Using nine combustion units, one worker could analyze 20 samples in a normal working day.

Standardizing the I-R Analyzer. The analyzer was standardized by injecting known amounts of pure carbon dioxide into the system after all carbon dioxide had been removed. For precise injections, a gas-tight syringe (Hamilton Company) was used. The carbon dioxide was injected into the system through a rubber septum similar to those used in gas chromatography.

A 0.1 to 10 ml injection of carbon dioxide was made through the septum at known temperature and atmospheric pressure. The volume of carbon dioxide was adjusted to standard conditions, and the weight of carbon injected was plotted against the meter reading of the I-R analyzer. A graph was drawn for each system volume and for several gain-control settings.

FIG. 1. A schematic diagram of the apparatus used for measuring the CO₂ resulting from the oxidation of organic matter.

Above: an oxidation unit containing the oxidized sample is shown in a temperature-regulated water bath. The oxidation unit includes the I-R analyzer; a filter for removing particles from the gas stream entering the analyzer; a circulating pump; a tube filled with KOH for removing CO₂ from the system; a manometer for measuring the pressure in the system; and a volume expansion tank.

Below: the combustion unit connected to the apparatus for removing inorganic CO₂ from the acidified sample. The combustion unit includes the oxidation flask and bellows valves connected to the flask by metal-to-glass "O" ring connectors. The unit was placed over a magnetic stirrer which vigorously stirred the water sample while CO₂-free air passed over it.

The standardization curve for a given volume and gain-control setting did not change as long as the analyzer was zeroed. The standardization was carried out with a volume of water in the system equal to the sample volume. The water was adjusted to pH 4 and all carbon dioxide removed from the system before the carbon dioxide was injected.

The carbon dioxide was injected into the system and equilibrium between the carbon dioxide in the gas and liquid phases was reached in 15 minutes. The amount of carbon dioxide in the water during standardization was the same as in a sample of equal volume when the both had the same temperature, pH, and carbon dioxide partial pressure. In cases where the difference between the amount of carbon dioxide dissolved in 1 ml of sample and 1 ml of air was sufficiently small, the use of water in the sample cell during standardization was unnecessary, thus saving considerable time.

The gain-control reduced or increased the meter deflection for a given amount of carbon dioxide; the higher the gain, the more the deflection. For high carbon dioxide concentrations, the large system volume was used in conjunction with a low gain-control setting.

Procedure for Removing Inorganic Carbon Dioxide from Sea Water Samples. Using the I-R method, the removal of inorganic carbon dioxide from sea water samples was accomplished by the following procedure:

(1). A teflon-encased magnetic stirring bar, 4 gm of potassium persulfate, and 0.5 ml of 0.5 M phosphoric acid were placed in the combustion flask with the water sample to be analyzed.

(2). The valves were attached to the combustion flask and the unit placed on the magnetic stirrer. The tubes from the carbon removal apparatus were attached to the unit and carbon dioxide-free air was passed over the samples for 30 minutes while the samples were rapidly stirred. The time necessary for removal of inorganic carbon dioxide was checked by attaching the combustion unit to the I-R analyzer, and no detectable carbon was present after 15 minutes. For routine analysis, however, the samples were vigorously stirred for 30 minutes to insure complete removal.

(3). The valves were tightly closed, the tubes were detached from the unit, and the flask placed in a steam autoclave at 10 psi, 115° C, for 30 minutes.

Procedure for Measuring Carbon Dioxide from the Combustion of Organic Carbon. The carbon dioxide resulting from the combustion of organic carbon was measured in the following manner:

(1). After the autoclave had been turned off and the pressure slowly reduced, the combustion unit was removed and placed in running tap water to hasten cooling the unit to room temperature (about 10 minutes).

(2). The unit was placed in a water bath at $20 \pm 1^\circ \text{C}$ and attached to the carbon dioxide measuring system.

(3). The carbon dioxide was removed by pumping gas through the KOH tube (requiring about 5 minutes with the large system volume of 5 liters, and less time with smaller volumes).

(4). The valves on the KOH tube were closed and the combustion unit valves opened. The water sample was vigorously stirred until the carbon dioxide in the sample reached equilibrium with the carbon dioxide in the system.

(5). The pump was turned off, and the reading on the analyzer meter was recorded. The amount of carbon dioxide or carbon in the system was calculated by using a standard curve. Further computations were unnecessary when the flask held the same

volume of water as was used during calibration, and when the carbon dioxide was in equilibrium between the gas and liquid phases of the system.

(6). Before the combustion unit was removed from the system, the valve connected to the manometer was opened and the pressure in the system noted. A low or negative pressure indicated a leak in the system or combustion unit. Pressures varied with different system volumes and with fresh and salt water samples.

Possible Range of Measurement Using the Infrared Method. The permissible range of measurement of organic carbon concentrations using the I-R method was relatively wide. The range was from 0.05 to 20 mg carbon. The low values were measured with the small system volume, the highest gain-control setting, and 250-ml samples. High concentrations of organic carbon were measured with the large system volume and low gain setting. High concentrations were determined by using small samples. When this was done, the 250-ml sample volume was reached by adding double distilled water. It was necessary to use the 250-ml volume in order to maintain standardization.

For special purposes, the system was modified to extend the range of measurement even further. Extremely high carbon values could be measured by using a larger system and the range of usefulness of the I-R method could be considered unlimited in that respect. For very large volumes, a higher pumping rate would have to be used to remove the carbon dioxide from the system in a reasonable length of time. The extent of the lower range was limited by the values obtained from the reagent blanks. The average blank value was 0.24 mg carbon (Table 1).

Sampling Methods Used in Field Studies. All water samples were taken at a depth of approximately 0.5 m and care was taken to exclude surface film from the samples. The 250-ml samples were placed in a clean 500-ml Erlenmeyer flask and frozen within 30 minutes after they were collected by placing the flasks in a dry ice and alcohol bath. The tops of the flasks were covered with aluminum foil. All samples collected were frozen unless they could be analyzed within an hour after sampling. The frozen samples were analyzed within a week after collection.

Duplicate samples were taken at each station. In the cases where only one value was reported, the duplicate sample was ruined by flask breakage or a failure in the procedure. Exceptions are noted where the data are reported.

River samples were obtained by lowering two 250-ml volumetric flasks clamped to the end of a pipe into the water from bridges over the rivers.

Results

EXPERIMENTS DESIGNED TO TEST THE I-R METHOD

Reagent Blanks and Known Compounds. To test the effectiveness of the I-R method of organic carbon analysis, blanks consisting of double distilled water and reagents were analyzed. The average blank value of 0.24 mg carbon ($\delta \pm 0.02$, $N = 12$) was subtracted from the result of each organic carbon analysis.

The accuracy of the method was tested for effectiveness by analyzing compounds with a known carbon content. Dr. C. G. Skinner selected compounds of varying degrees of toughness for this analysis. The compounds were weighed on aluminum foil without drying and were placed in oxidation flasks with double distilled water. The water-insoluble compounds had a tendency to adhere to the walls of the flask above the water level and after oxidation could still be seen although the compounds in the water had

disappeared. The results of these analyses (Table 1) indicate a 95% average recovery of carbon from the compounds tested.

Chlorella Samples. *Chlorella* samples obtained from Dr. Jack Myers were also analyzed. The results of *Chlorella* analyzed by the I-R method were compared to results of *Chlorella* analyzed by other methods (Table 2).

The *Chlorella* used had been freeze-dried and stored in vials containing nitrogen. *Chlorella* preserved in this fashion is very hygroscopic. The first analysis was made on a sample that had been previously opened and may have picked up moisture. For the last three analyses, a portion of a sample was used for which Dr. Myers had obtained a commercial elemental analysis. The results of the commercial analysis are reported in Table 2.

Weighing the *Chlorella* samples was difficult as the samples rapidly gained weight while on the balance. This possibly contributed to the difference in values found in the last two samples. The discrepancy was small, and the analysis of *Chlorella* by the I-R method agreed with other methods of analysis.

TEXAS BAYS

Data on organic concentrations in the waters of Texas bays and rivers are given in Figs. 2-5. Studies of the marine environment have shown that there is a low concentration of organic matter in sea water. Reviewing the literature on the subject, Duursma (1960) reported that the range of organic matter in the open sea is 0.04 to 8 mg/liter.

The values of organic matter reported in this investigation were from samples taken

TABLE 1
Recovery of carbon from known compounds

Compound	mg compound added	mg C added	mg C recovered	per cent recovery
Dextrose	8.21 ± .02	3.28	3.11 ± .05	95
	10.69 ± .02	4.28	4.09 ± .05	96
	7.65 ± .02	3.06	2.96 ± .05	97
Diphenylurea	2.41 ± .02	1.77	1.67 ± .05	94
	3.71 ± .02	2.73	2.44 ± .05	89
	5.37 ± .02	3.95	3.66 ± .05	93
Benzoic Acid	10.39 ± .02	7.15	7.06 ± .05	99
	6.62 ± .02	4.56	4.46 ± .05	98
	3.91 ± .02	2.69	2.53 ± .05	94
6-Mercaptopurine	5.18 ± .02	1.83	1.66 ± .05	91
	3.75 ± .02	1.32	1.25 ± .05	95
	6.80 ± .02	2.40	2.25 ± .05	93
Pregnane	4.89 ± .02	3.21	3.18 ± .05	99
	4.63 ± .02	3.04	2.74 ± .05	90
	5.30 ± .02	3.48	3.44 ± .05	99
DL Tryptophane	2.18 ± .02	1.41	1.37 ± .05	97
	2.22 ± .02	3.04	1.34 ± .05	91
	3.28 ± .02	3.48	2.01 ± .05	95
Pteridine	2.32 ± .02	1.17	1.11 ± .05	95
	2.37 ± .02	1.19	1.17 ± .05	98
	2.19 ± .02	1.10	1.00 ± .05	91

$\bar{X} = 95$
standard error (S.E.) = 1

TABLE 2

Recovery of carbon from *Chlorella* by the I-R analysis method compared to two other methods of recovery. The first was a wet combustion method used by Corcoran and the other was from commercial elemental analysis

I-R method	Wet combustion
41.8%	41.6%
42.2%	43.5%
43.0%	37.7%
41.7%	
42.2%	
I-R method	Elemental analysis
49.1%	49.2%
47.1%	48.5%
46.1%	

off-shore in the Gulf of Mexico and in estuarine bays, not in the open sea. However, samples from Texas bays had a much higher organic content than samples from the Gulf of Mexico. Fox, Isaacs, and Corcoran (1952) reported that some off-shore water in California contained 20 mg carbon/liter, and Collier et al. (1953) reported high concentrations in Galveston Bay, Texas.

The samples analyzed contained dissolved and suspended organic matter. This was done in order to include all the organic matter in water. The few samples that were filtered (Table 4) show a high per cent of the total organic matter to be in dissolved and colloidal form. Although the percentage was high, it was lower than usually found in sea water (Duursma, 1960). The relatively high amount of particulate matter may

TABLE 3
Analyses of samples

Source of samples	Mg C/L
*PUERTO RICO	
Brine pool where salt water was being evaporated for salt	118
	124
Marine source water from <i>Thalassia</i> flat near shore outside a Mangrove Swamp	1.0
Marine water entering over the mud of a Mangrove Swamp (Rhizopora)	5.0
Marine water leaving a Mangrove Swamp	30.2
	25.8
MISCELLANEOUS AREAS	
Laguna Madre Tamaulipas, Mexico; sampled May, 1961	51.6
	53.6
Pond in Zilker Park, Austin, Texas; sampled April, 1962	69.1
	73.2
Littlefield Fountain, University of Texas, Austin (on campus); sampled April, 1961	38.0
Aged sea water obtained from Port Aransas, Texas, July, 1959, and kept in the dark in a glass carboy; analyzed November, 1961	2.2
	2.5
	2.4
	2.5
	2.6
Waller Creek at the University of Texas; sampled April, 1961	7.9
	8.1
Fresh water pond south of Aransas Pass, Texas; sampled 10 May, 1960	90.0
	105.0

* The samples were not frozen and were analyzed 4 to 8 days after they were taken, April 2-6, 1962. The six-day biological oxygen demand for the rainforest samples was 0.22 mg O₂/liter (personal communication with Dr. H. T. Odum).

have been due to the high populations of bacteria found in these bays (Oppenheimer and Jannasch, 1962).

Sea water kept in a darkened glass carboy for over two years by Dr. Austin Phelps had 2.2 to 2.6 mg carbon/liter. This value is much larger than those of previous reports

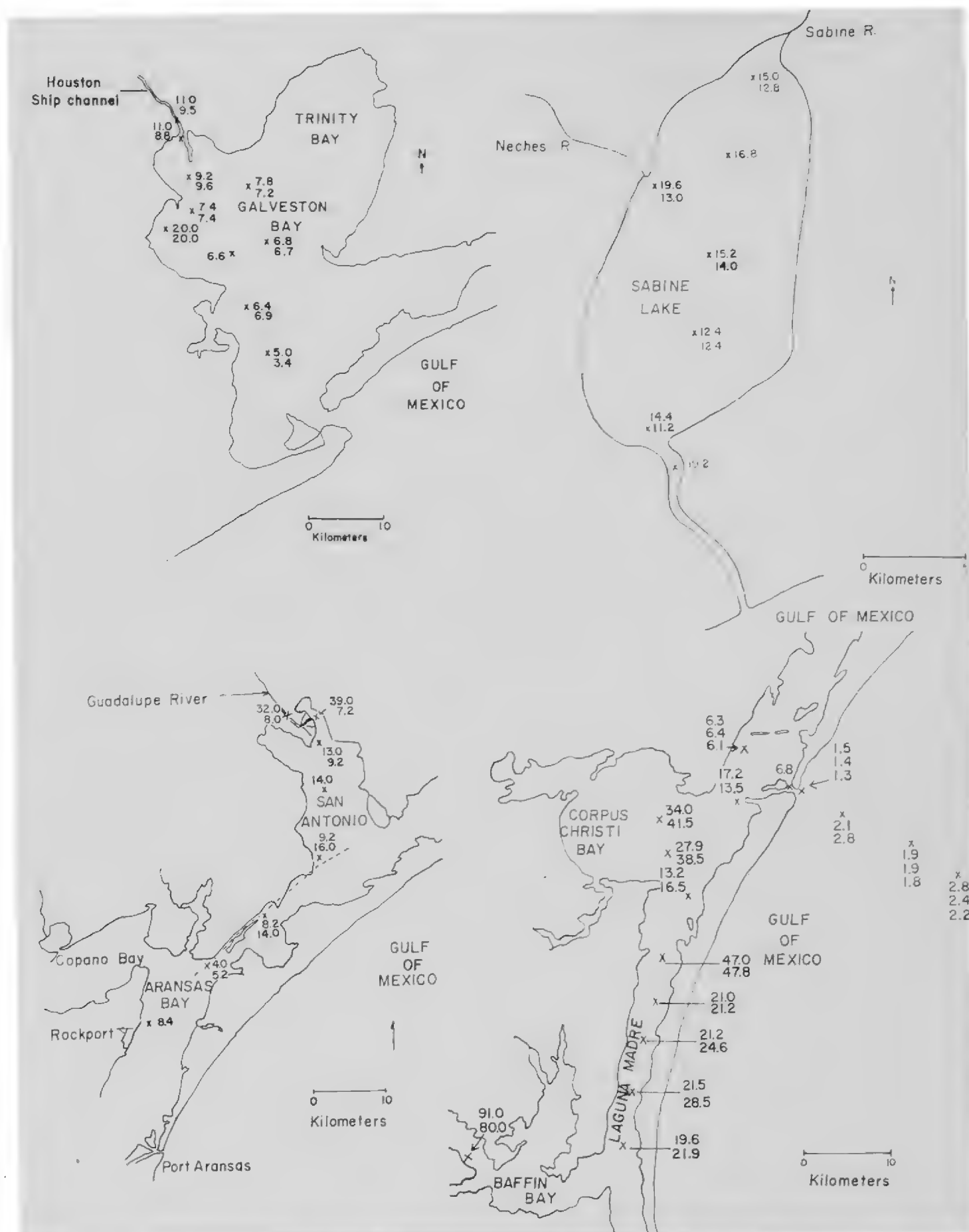


FIG. 2. Organic carbon data in mg carbon per liter of water. Sabine Bay on the Texas-La. border, sampled 7 April, 1962. Galveston Bay, Texas, sampled 24 February, 1962. San Antonio and Aransas Bays, Texas sampled 10 March, 1962. Central coast area near Corpus Christi, Texas: Baffin Bay was sampled 23 April, 1960, the Gulf of Mexico was sampled 20 August, 1960, and the other samples were obtained 17-18 May, 1960.

for the action of marine bacteria on organic matter in marine water, especially as a surface was available for growth (Zobell, 1946; Waksman, Carey, and Reuszer, 1933; and Rakestraw, 1947).

The highest levels of organic carbon approached or exceeded 100 mg carbon/liter, and were found in samples from three areas: Baffin Bay, Texas (Fig. 2); a fresh water pond near Aransas Pass, Texas (Table 4); and in a man-made brine pool in Puerto Rico (Table 3).

TABLE 4
Organic carbon content of filtered samples

Source of sample	Total carbon mg C/liter	Dissolved* mg C/liter	Dissolved* per cent
Fresh water pond south of Aransas Pass, Texas; sampled 15 May, 1960	90.0 105.0	55.0 67.0	61.0 64.0
Sea water from Aransas Pass, Texas; sampled 20 August, 1960	2.6 1.4	1.3 0.9	50.0 64.0
Baffin Bay, Texas; sampled 23 April, 1960	91.5 80.0	39.0 34.0	42.0 43.0

The samples were passed through a millipore type H-A filter (average pore size, 0.45 microns). Distilled water, which had been passed through a filter, was used in place of the usual blank value.

* Dissolved and colloidal fractions smaller than 0.45 microns.

Values of approximately half of this concentration were found in samples taken from the Laguna Madre of Mexico (Table 3); the Laguna Madre of Texas (Fig. 2); from oil well bleed water near Corpus Christi, Texas (Fig. 3); and from a pond in Zilker Park, Austin, Texas (Table 3).

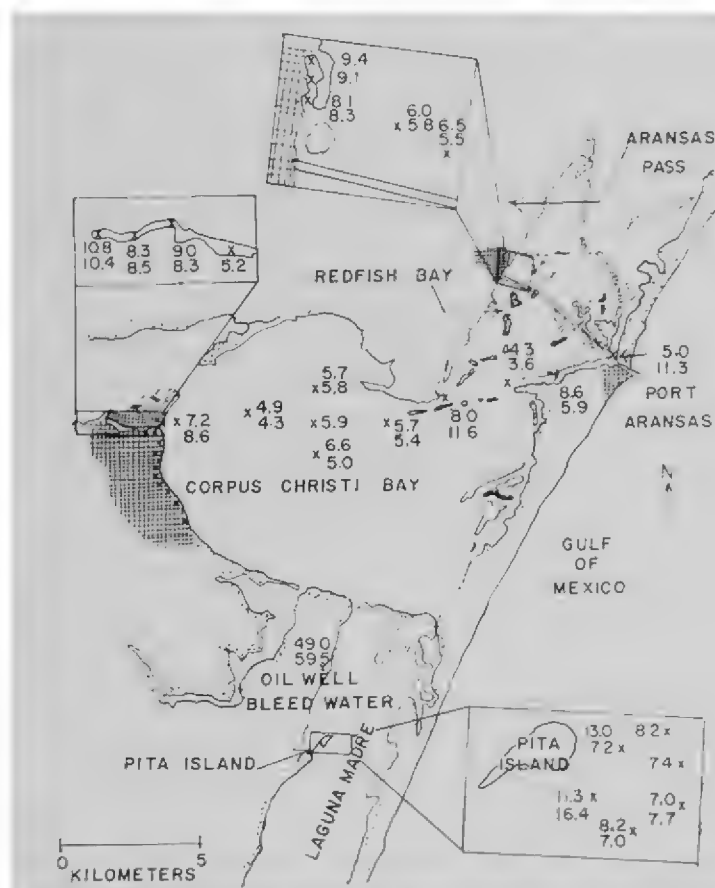


FIG. 3. Section of the coast near Corpus Christi Bay, Texas, sampled during 12 and 17 February, 1962. All data are presented in mg carbon/liter.

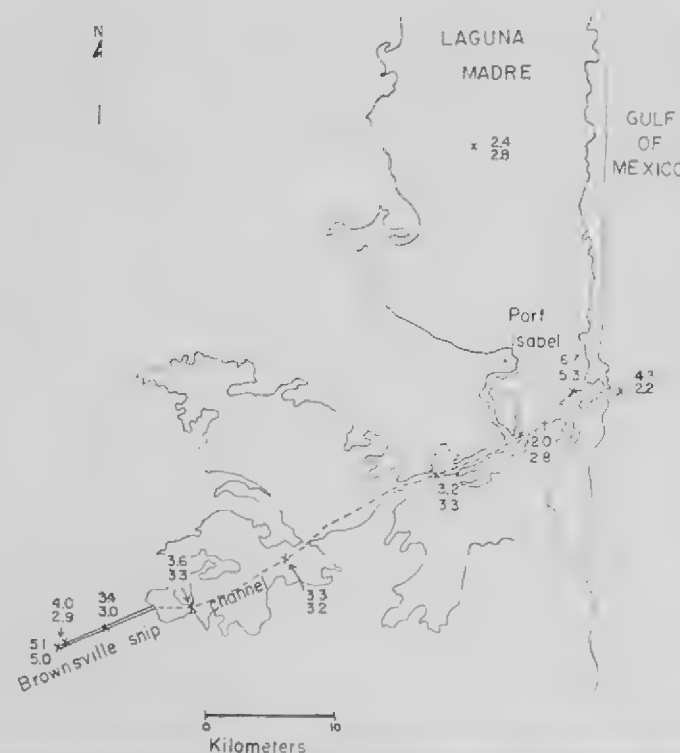


FIG. 4. Area of the Texas coast near Port Isabel. Most of the samples were collected near the Brownsville Ship Channel. Samples were taken 31 March, 1962. The data are presented in mg carbon/liter.

No measurable amount of organic carbon could be found in samples from two springs in limestone formations (Fig. 5). If it is assumed that water entering the limestone formation contained some organic matter, then the question is raised as to what mechanism removed it from the water before it emerges at the springs. Odum (1957) postulated that underground respiration removed organic matter from the water at Silver Springs, Florida. He supports this thesis with evidence that oxygen content of the water is higher when the flow of water is greater.

Possible Formation and Fate of Organic Matter. The major sources of dissolved organic carbon in water were primary production, runoff, and industrial or domestic wastes.

The high values in oil well bleed water (Fig. 3) were an example of industrial waste.

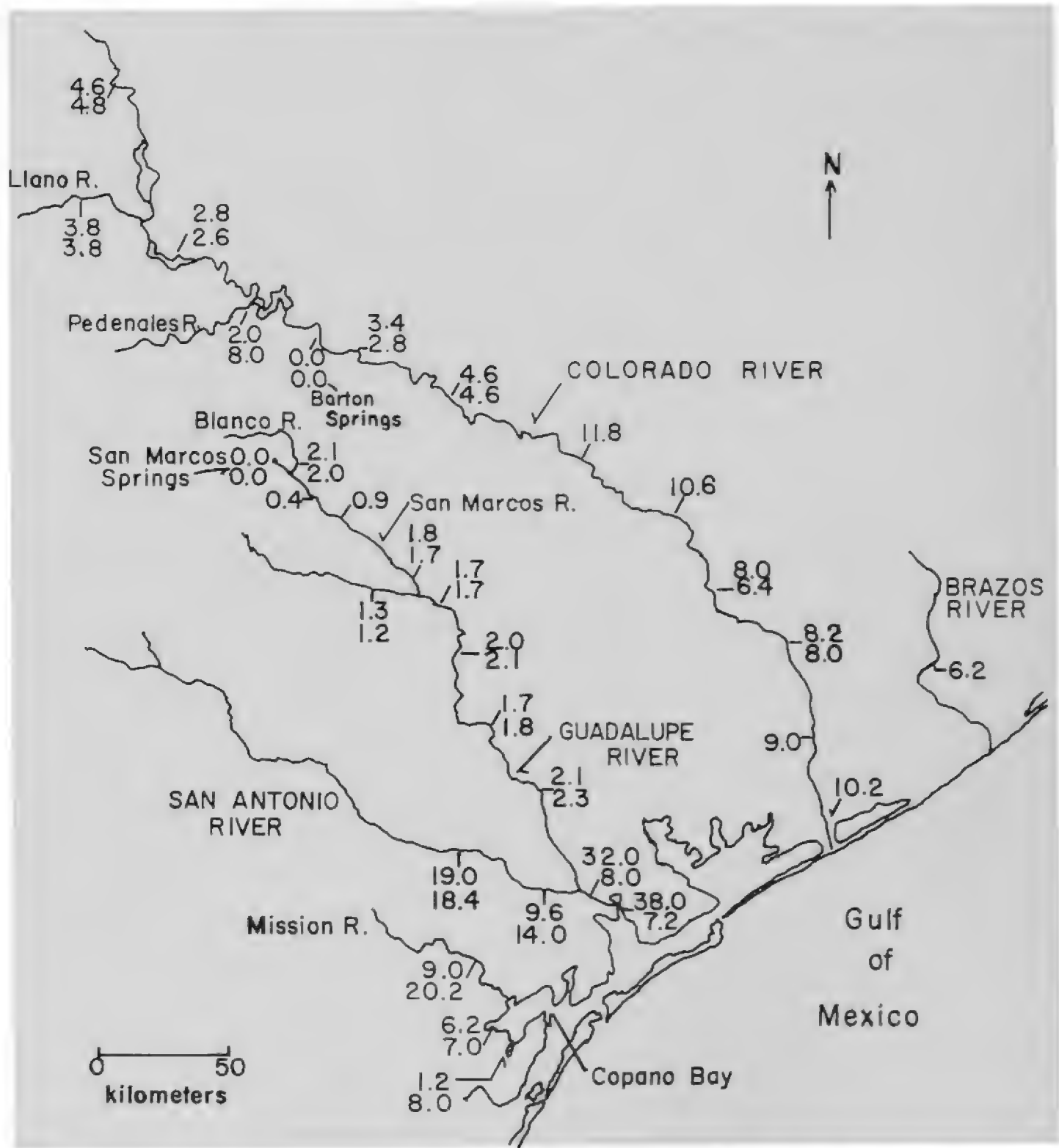


FIG. 5. Samples taken from rivers in Texas. The Guadalupe and San Marcos River samples were taken 11 March, 1962. The Colorado River samples were taken 8 April, 1962. The samples from the Mission River and Copano Bay were obtained 15 April, 1962. All data are given in mg carbon per liter of water.

Each inhabited community along the two rivers that were sampled probably added domestic wastes to the rivers. One example of high concentrations of organic carbon probably due entirely to primary production was the pond sampled in Zilker Park, Austin, Texas. Water was piped into the artificial pond from Barton Springs, which had no measurable organic carbon. There was no drainage where organic matter could be added by runoff and the pond had no outlet. Water was added only to maintain the water lost by evaporation or seepage.

Reduced flushing accompanied by evaporation may concentrate organic matter in water. Baffin Bay, Mexican Laguna Madre, and the salt pool in Puerto Rico had little flushing and high concentrations of organic matter. High concentration of organic matter near 100 mg/liter was found in the pond south of Aransas Pass, Texas. At the time this pond was sampled, there was no visible water flowing into it and the narrow connection between it and Redfish Bay probably reduced flushing.

Another factor contributing to high organic concentration in water was reduced community respiration. Respiration may be affected by high salt concentration or possibly by domestic and industrial wastes. In theory, an unbalanced community metabolism is a necessary requirement for accumulating high concentrations of organic matter. The rate of organic matter increase from all sources must be higher than the rate of destruction and export. Probably both an unbalanced metabolism and a low flushing rate are necessary.

Waste materials may drastically influence primary production in two ways: destroying the producers by detrimental actions on the plants, and by stimulating primary production with the addition of nutrients. Perhaps to a lesser extent, runoff may play a similar role. The relatively low organic concentrations in samples from the Llano and Colorado Rivers (Fig. 5) suggest that runoff did not add a great deal of organic matter to the water. Primary production and wastes may have been the major contributors to the increasing concentrations downstream. The high concentrations found in samples from the San Antonio River (Fig. 5) may have been due to domestic wastes from San Antonio, Texas, or from primary production stimulated by nutrients in the wastes. The increase in concentration of organic matter at the mouth of the Guadalupe River (Fig. 5) may have been due to bleed water or actual oil reaching the river from the large number of oil wells in that vicinity.

The constant destruction of organic matter by microbes requires a constant influx if a high level of organic matter is maintained. Results of production and respiration measurements in the Texas bays by the diurnal-curve method (Odum and Wilson, 1962) show that the bays with rivers flowing into them often had a respiration rate higher than the rate of production. The difference must have been due to organic matter supplied by the rivers.

Acknowledgments

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In addition to providing working space and the equipment for much of the work reported, Dr. Jack Myers' constructive criticisms and suggestions were invaluable. Organic compounds used to test the accuracy of the infrared method were selected and provided by Dr. C. G. Skinner.

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Seasonal Plankton Productivity in the Surfzone of a South Texas Beach¹

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Abstract

Seasonal change in the oxygen metabolism of the microconstituents of surf water at Mustang Island, Texas were measured using a light-dark bottle method. The gross photosynthesis, net photosynthesis and respiration of plankton reached highest levels during summer and fall and lowest levels during winter. Respiration during summer averaged 1.05 g O₂/m³ per day and was four times the average winter respiration. Net photosynthesis during summer averaged 0.99 g O₂/m³ per day and was nearly three times the average winter rate. A net photosynthesis occurred throughout the year except during spring, when periodic bursts of high spring respiration coincided with large numbers of decapod larvae in the surf water. Seasonal change in temperature, salinity and beach water currents are also related to the seasonal change in plankton productivity.

Introduction

Sandy beaches that are subject to strong wave action constitute a considerable portion of the earth's shorelines. Sand beach environments can be distinguished biologically from other coastal environments, such as rocky coastlines, by the presence of infaunas as dominant resident populations and the virtual absence of macrophytes (Hedgpeth, 1957).

Biological studies of sandy beaches have dealt primarily with the infaunas and the adaptations of species to the rigors of the environment. An extensive literature has accumulated on the physiography of sand beaches and their biota (see Hedgpeth, 1957). The work of Koepcke and Koepcke (1952) on North Peruvian sand beach faunas considers the over-all ecology of the sand beach environment.

Quantitative studies of the standing crop of organisms characteristic of sand beaches have been limited almost entirely to the molluscan infauna (Fitch, 1950; Loesch, 1957). Studies of the organisms present in the water mass are qualitative and mainly consider the relative seasonal abundance of fishes (Pearse, Humm and Wharton, 1942; Gunter, 1945; and Gunter, 1958).

Other than descriptive material, little attention has been fixed on the plankton forms that are constantly swept over the sand beach environment by currents and tides. The food chains constructed by Koepcke and Koepcke (1952) indicate that a large percentage of the molluscan infauna and *Emerita* depend on plankton and organic detritus, as do plankton-feeding fishes such as anchovies.

In this paper data on salinity, temperature and the seasonal productivity of plankton are reported for the surfzone waters of the beach at Mustang Island, Texas.

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The beach studied is oriented approximately along a northeast-southwest axis. A series of 10 sampling stations were set up at one-mile intervals along Mustang Island, beginning at Caldwell Pier, Port Aransas, and ending 10 miles to the southwest.

The Environment

The Texas coastal plain is noted for its shallow seaward gradient (Shepard, 1950; Hedgpeth, 1953) and sharp drop-offs are not encountered in the surfzone (Fig. 1). Although the action of seasonal currents drastically alter the absolute physiography of the Texas beach, profiles below high tide levels (as indicated in Fig. 1) are maintained in a relative state of constancy. For this reason all samples of water were obtained from the first longshore-trough, where water depth varied from about two and one-half to three and one-half feet during a normal tidal cycle. The distance offshore varied from about 80 to 150 feet.

Strong longshore currents, either in a northward or southward direction, occur throughout the year and are related to the direction of prevailing winds. Thus, during spring and particularly summer, southerly winds create a northward set of the inshore currents, whereas during winter, northerly winds induce a southward longshore current. East by south-easterly winds, which occur frequently during all seasons, coincide with both northward and southward longshore currents. Under these circumstances, other factors, such as major hydrographic features of the inshore shelf waters probably interact with wind to determine the direction of longshore currents.

No attempt was made to characterize the beach sediments or infauna; the data reported deal exclusively with salinity, temperature and plankton productivity, each of which is little affected by the substratum.

Seasonal Salinity Patterns

Salinity of the water from the first longshore trough was determined for each of the ten stations, whenever possible, on a weekly basis from October 13, 1959 through November 9, 1960. Triplicate Mohr titrations were performed on each sample and the mean salinity recorded to the nearest 0.01 ‰. Analysis of a series of samples of 30 ‰ gave a mean deviation of ± 0.02 ‰ and a maximum deviation of ± 0.06 ‰ ($N = 9$).

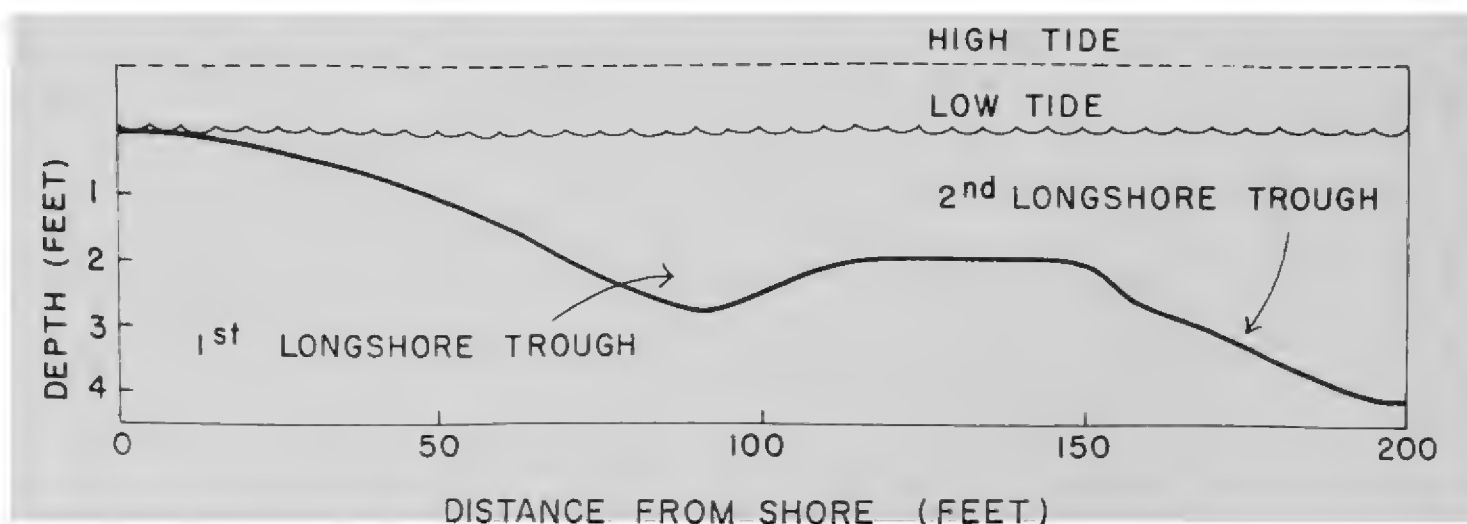


FIG. 1. Typical beach profile south of Port Aransas, Mustang Island, Texas. Often a fringe pool is created in the first 30 feet of the surf. As one proceeds along the beach the bars and troughs vary slightly in their distance offshore. As a result, bars are not continuous and troughs intermingle.

TABLE 1

Seasonal salinity and temperature records. Non-bracketed values are salinities in ‰. Bracketed values are temperatures in degrees centigrade. Stations 1-10 represent one-mile intervals commencing at Caldwell Pier, Port Aransas, Texas and extend southward along Mustang Island

Date	1	2	3	4	Station 5	6	7	8	9	10	Mean
Oct. 13, 1959	31.06 (29.2)	31.12 (29.2)	31.27 (29.2)	31.28 (29.2)	31.21 (29.2)	31.32 (29.2)	31.44 (29.2)	31.46 (29.2)	31.46 (29.2)	31.49 (29.2)	31.31 (29.2)
Oct. 21, 1959	27.77 (24.6)	28.82 (25.1)	29.14 (25.1)	29.25 (25.1)	29.50 (25.1)	29.57 (25.1)	29.58 (25.1)	29.58 (25.1)	29.58 (25.1)	29.57 (25.1)	29.24 (25.05)
Oct. 31, 1959	30.00 (26.0)	30.62 (26.0)	30.72 (26.5)	30.60 (26.5)	30.62 (26.6)	30.56 (26.6)	30.72 (26.8)	30.60 (26.9)	30.67 (26.9)	30.72 (26.9)	30.58 (26.57)
Nov. 11, 1959	30.98 (21.0)	30.96 (21.1)	30.99 (21.1)	31.10 (21.1)	31.16 (21.1)	31.12 (21.1)	31.12 (21.2)	31.09 (21.1)	30.98 (21.1)	30.94 (21.1)	31.04 (21.10)
Nov. 20, 1959	29.14 (16.5)	29.10 (16.4)	29.20 (16.3)	29.19 (16.5)	29.23 (16.4)	29.25 (16.6)	29.28 (16.8)	29.25 (16.8)	29.40 (16.8)	29.36 (16.8)	29.24 (16.59)
Dec. 1, 1959	31.24 (18.0)	31.24 (18.1)	31.37 (18.0)	31.48 (18.1)	31.50 (18.1)	31.48 (18.3)	31.52 (18.3)	31.48 (18.3)	31.83 (18.1)	31.91 (18.1)	31.51 (18.14)
Dec. 7, 1959	31.28 (15.1)	31.26 (15.1)	31.32 (15.2)	31.32 (16.1)	31.30 (16.1)	31.30 (16.1)	31.32 (16.1)	31.30 (16.1)	31.45 (16.1)	31.43 (16.1)	31.33 (15.81)
Dec. 11, 1959	33.19 (20.0)	33.26 (20.0)	33.26 (20.0)	33.26 (19.8)	33.26 (19.8)	33.30 (19.8)	33.30 (19.8)	33.30 (19.8)	33.30 (19.8)	33.34 (19.8)	33.28 (19.86)
Dec. 22, 1959	31.86 (17.9)	31.97 (17.9)	32.02 (17.9)	32.17 (18.0)	32.04 (18.0)	31.97 (18.0)	32.00 (18.0)	32.00 (18.1)	32.00 (18.1)	32.04 (18.1)	32.01 (18.00)
Jan. 7, 1960	29.61 (12.0)	29.59 (12.0)	29.39 (12.5)	29.30 (12.4)	28.99 (12.4)	29.60 (12.4)	28.83 (12.6)	28.60 (13.1)	28.50 (13.1)	28.58 (13.0)	29.10 (12.55)
Jan. 12, 1960	29.73 (18.0)	29.80 (18.0)	29.65 (17.9)	29.69 (17.9)	29.74 (18.0)	29.80 (18.1)	29.76 (18.1)	29.85 (18.1)	29.87 (18.1)	29.84 (18.1)	29.77 (18.03)
Jan. 20, 1960	27.84 (13.0)	28.16 (12.8)	28.58 (12.8)	28.76 (12.7)	28.84 (12.5)	29.14 (12.3)	29.14 (12.2)	29.14 (12.2)	29.14 (12.0)	29.10 (11.9)	28.78 (12.44)
Jan. 29, 1960	29.20 (14.8)	31.28 (14.8)	31.25 (14.9)	31.26 (14.8)	31.26 (15.0)	31.38 (15.0)	31.25 (15.1)	31.04 (15.2)	31.02 (15.2)	31.06 (15.2)	31.00 (15.00)
Feb. 5, 1960	32.79 (14.1)	32.88 (14.1)	32.94 (14.1)	32.92 (14.0)	33.09 (14.0)	33.09 (14.0)	33.09 (14.1)	33.24 (13.9)	33.13 (13.9)	33.28 (13.9)	33.05 (14.01)
Feb. 18, 1960	32.15 (16.1)	32.15 (16.1)	32.45 (16.1)	32.34 (15.9)	32.62 (15.9)	32.60 (15.6)	32.84 (15.2)	33.61 (15.1)	34.05 (15.1)	34.22 (15.1)	32.90 (15.62)
Feb. 26, 1960	30.24 (13.8)	31.32 (13.9)	31.67 (13.9)	31.77 (13.8)	31.84 (13.8)	32.80 (13.7)	32.93 (13.7)	33.50 (13.7)	32.90 (13.7)	33.06 (13.7)	32.20 (13.77)
Mar. 4, 1960	24.77 (12.8)	29.39 (12.9)	29.76 (13.0)	29.81 (13.1)	29.93 (13.2)	29.95 (13.3)	30.00 (13.4)	30.04 (13.3)	30.09 (13.3)	30.13 (13.3)	29.39 (13.16)
Mar. 9, 1960	29.30 (13.5)	29.00 (13.5)	29.09 (13.5)	28.91 (13.6)	28.91 (13.7)	28.91 (13.8)	28.93 (13.8)	28.96 (13.9)	28.04 (13.9)	28.04 (13.9)	28.81 (13.71)
Mar. 16, 1960	28.98 (15.6)	28.59 (15.6)	28.23 (15.6)	27.90 (15.6)	27.77 (15.7)	27.47 (15.8)	27.71 (15.7)	28.40 (15.7)	28.77 (15.6)	29.07 (15.5)	28.29 (15.64)
Mar. 25, 1960	33.52 (16.7)	33.72 (16.7)	33.67 (16.7)	33.85 (16.7)	33.85 (16.7)	33.91 (16.8)	34.04 (16.7)	33.91 (16.8)	33.85 (16.8)	34.00 (16.7)	33.83 (16.73)
Mar. 31, 1960	30.47 (20.5)	30.60 (20.5)	30.69 (20.6)	30.65 (20.6)	30.65 (20.7)	30.69 (20.8)	30.75 (20.8)	30.69 (20.8)	30.93 (21.0)	30.88 (21.0)	30.70 (20.73)
Apr. 8, 1960	31.77 (20.0)	31.77 (20.0)	31.96 (20.0)	31.96 (20.0)	32.20 (19.9)	32.62 (19.8)	32.39 (19.7)	32.43 (19.7)	32.24 (19.7)	32.39 (19.8)	32.17 (19.86)
Apr. 13, 1960	32.94 (20.5)	32.96 (20.5)	32.99 (20.4)	32.96 (20.4)	33.07 (20.4)	33.09 (20.4)	33.11 (20.5)	33.22 (20.5)	33.26 (20.3)	33.22 (20.4)	33.08 (20.43)
Apr. 19, 1960	31.41 (22.0)	31.50 (22.0)	31.80 (22.1)	32.75 (22.1)	31.76 (22.1)	31.86 (22.2)	31.86 (22.2)	31.86 (22.3)	31.97 (22.3)	32.00 (22.3)	31.89 (22.16)
Apr. 27, 1960	29.99 (26.0)	30.03 (26.0)	30.20 (26.0)	30.18 (26.2)	30.25 (26.2)	30.18 (26.2)	30.37 (26.3)	30.56 (26.3)	30.56 (26.3)	30.56 (26.4)	30.29 (26.19)
May 5, 1960	27.17 (25.0)	27.26 (25.0)	27.30 (25.0)	27.49 (25.0)	27.36 (25.0)	27.55 (24.9)	27.55 (24.9)	27.83 (24.6)	27.96 (24.5)	28.05 (24.5)	27.55 (24.84)
May 13, 1960	32.45 (23.5)	32.41 (23.5)	32.40 (23.4)	32.45 (23.4)	32.43 (23.3)	32.51 (23.3)	32.63 (23.3)	32.72 (23.2)	32.56 (23.2)	32.51 (23.2)	32.51 (23.33)

TABLE 1—Continued

Date	1	2	3	4	Station 5	6	7	8	9	10	Mean
May 20, 1960	32.89 (26.0)	33.64 (26.0)	33.64 (26.1)	33.79 (25.5)	33.98 (25.5)	34.21 (25.2)	34.36 (25.2)	34.17 (25.1)	34.59 (25.0)	34.59 (25.0)	33.99 (25.40)
May 28, 1960	32.43 (28.5)	32.56 (28.5)	32.89 (28.6)	32.98 (28.7)	33.18 (28.7)	33.43 (28.7)	33.43 (28.8)	33.42 (28.8)	33.49 (28.8)	33.51 (28.9)	33.13 (28.70)
May 31, 1960	33.00 (28.8)	33.05 (28.8)	33.11 (28.9)	33.12 (29.0)	33.18 (29.0)	33.18 (29.0)	33.14 (29.1)	33.20 (29.1)	33.29 (29.1)	33.31 (29.1)	33.16 (28.99)
June 9, 1960	34.82 (32.0)	34.99 (32.1)	34.99 (32.1)	35.01 (32.2)	35.14 (32.2)	35.08 (32.2)	35.14 (32.3)	35.19 (32.3)	35.10 (32.4)	35.36 (32.4)	35.08 (32.22)
June 16, 1960	35.49 (29.5)	35.64 (29.5)	35.68 (29.3)	35.64 (29.3)	35.68 (29.3)	35.75 (29.5)	35.68 (29.4)	35.82 (29.5)	35.80 (29.5)	35.82 (29.5)	35.70 (29.43)
June 28, 1960	34.60 (30.2)	34.97 (30.2)	34.97 (30.4)	34.88 (30.4)	34.97 (30.5)	35.34 (30.6)	35.71 (30.6)	35.71 (30.6)	36.51 (30.8)	36.46 (30.8)	35.41 (30.51)
July 7, 1960	38.29 (32.5)	38.49 (32.5)	38.44 (32.5)	38.29 (33.0)	38.29 (33.0)	38.68 (33.0)	37.52 (33.0)	38.29 (32.5)	38.49 (32.5)	38.49 (32.5)	38.33 (32.70)
July 14, 1960	35.95 (31.1)	36.18 (31.1)	36.34 (31.2)	36.18 (31.3)	36.36 (31.5)	36.53 (31.4)	36.40 (31.5)	36.64 (31.5)	36.62 (31.4)	36.35 (31.5)	36.36 (31.35)
July 22, 1960	37.62 (31.1)	37.54 (31.2)	37.66 (31.2)	37.64 (31.4)	37.77 (31.4)	37.73 (31.5)	37.66 (31.5)	37.66 (31.7)	37.66 (31.7)	 (31.8)	37.66 (31.45)
July 28, 1960	36.88 (34.0)	36.61 (33.9)	36.84 (33.9)	36.86 (33.8)	36.78 (33.8)	37.01 (33.6)	36.90 (33.6)	36.94 (33.6)	37.01 (33.5)	36.97 (33.5)	36.88 (33.72)
Aug. 8, 1960	37.01 (29.8)	37.04 (29.8)	37.08 (29.8)	37.12 (29.6)	37.08 (29.5)	37.04 (29.4)	37.12 (29.4)	37.04 (29.3)	37.08 (29.3)	37.03 (29.3)	37.06 (29.52)
Aug. 17, 1960	38.61 (31.0)	38.61 (31.0)	38.67 (31.0)	38.73 (31.2)	38.75 (31.2)	38.82 (31.2)	38.82 (31.3)	38.79 (31.3)	38.82 (31.4)	38.81 (31.4)	38.74 (31.20)
Aug. 25, 1960	37.45 (29.8)	37.38 (29.8)	37.48 (29.8)	37.44 (29.8)	37.50 (29.8)	37.52 (29.9)	37.52 (29.9)	37.46 (29.9)	37.50 (29.9)	37.54 (30.0)	37.49 (29.86)
Sept. 1, 1960	36.45 (31.0)	36.57 (31.0)	36.69 (31.0)	36.77 (31.0)	36.85 (31.2)	36.87 (31.2)	36.89 (31.3)	37.03 (31.3)	37.09 (31.4)	37.09 (31.4)	36.83 (31.18)
Sept. 8, 1960	33.40 (29.8)	33.58 (29.8)	33.60 (29.8)	33.72 (29.9)	33.70 (29.9)	33.74 (29.9)	33.80 (29.9)	33.98 (30.0)	34.04 (30.0)	34.08 (30.0)	33.76 (29.90)
Sept. 16, 1960	30.69 (28.8)	30.73 (28.8)	31.02 (28.9)	31.06 (28.9)	31.00 (28.9)	30.63 (28.9)	30.79 (29.0)	30.75 (29.0)	30.73 (29.0)	30.89 (29.0)	30.83 (28.92)
Sept. 28, 1960	31.06 (27.5)	31.10 (27.5)	31.21 (27.3)	31.25 (27.3)	31.39 (27.2)	31.37 (27.2)	31.25 (27.2)	31.39 (27.1)	31.45 (27.0)	31.43 (26.9)	31.29 (27.22)
Oct. 7, 1960	34.02 (28.2)	34.10 (28.2)	34.16 (28.2)	34.20 (28.4)	34.12 (28.4)	34.20 (28.5)	34.16 (28.6)	34.20 (28.6)	34.22 (28.6)	34.37 (28.7)	34.18 (28.44)
Oct. 14, 1960	36.48 (28.0)	32.71 (28.0)	32.59 (28.0)	32.73 (28.2)	32.63 (28.2)	32.63 (28.2)	32.69 (28.3)	32.75 (28.4)	32.81 (28.4)	32.83 (28.5)	33.09 (28.22)
Nov. 9, 1960	31.11 (24.8)	31.24 (24.6)	31.28 (24.4)	31.26 (24.2)	31.42 (24.0)	31.34 (24.0)	31.28 (24.0)	31.36 (23.9)	31.44 (23.9)	31.42 (23.9)	31.32 (24.17)

The mean salinity for each station and the average salinity of all 10 stations are recorded in Table 1. Seasonal variations of salinity are apparent (Fig. 2) and as expected (Gunter, 1958), highest salinities occurred in July and August and lowest salinities in the winter and spring months. Abrupt fluctuations in salinity probably represent the mixing of brackish waters from the Texas bays with gulf shelf water. As a rule, outflow from the south Texas bays through Aransas Pass, Port Aransas is directed southward and sets on the Mustang Island beach 2 to 5 miles south of the pass (as indicated by drift bottles released in the mouth of the pass). Since northerly winds favor a southward longshore current, bay and gulf waters commonly mix along the beach and result in lowered salinities during winter. In contrast, during summer when longshore currents are often directed to the north, mixing of bay and gulf waters occurs offshore and, as a result, beach salinities along Mustang Island are more characteristic of Gulf of Mexico water.

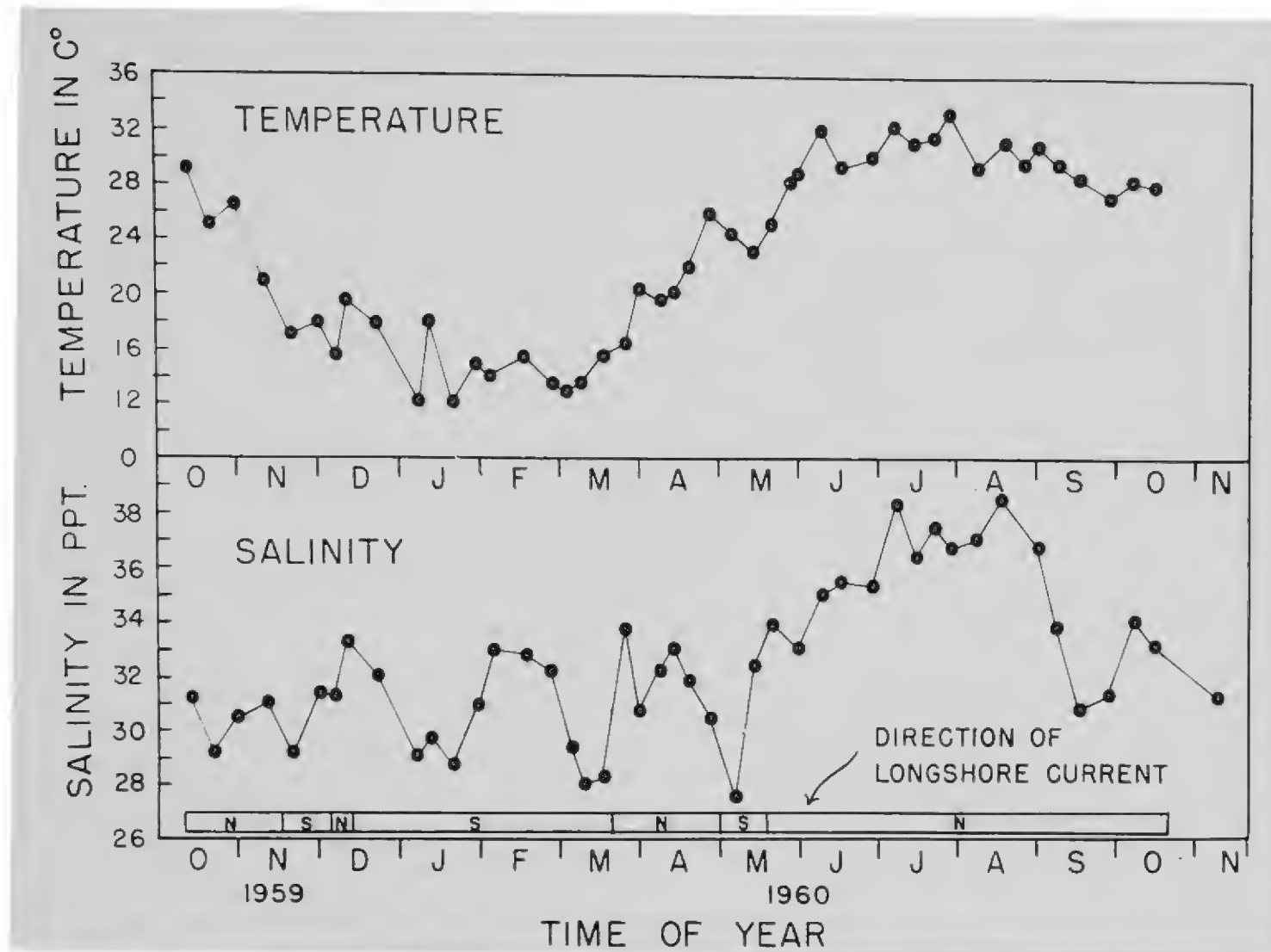


FIG. 2. Seasonal changes in temperature and salinity of the surf south of Port Aransas, Mustang Island, Texas. Direction of longshore current is to a large extent the result of prevailing winds. Thus a northward set of current results from southerly winds. Salinities and temperatures are the averages of 10 samples collected at one-mile intervals along the beach. Raw data are recorded in Table 1.

However, during summer, southward longshore currents occur sporadically during periods of easterly winds. Hence, mixing of bay and gulf waters may occur during periods of high bay salinities; as a result beach salinities may exceed normal values for offshore gulf waters (Fig. 2, see July and August).

Examination of the data for each sampling station reveals that horizontal linear salinity gradients along the beach were prevalent only during the months of January, February, March, April and May. Salinity gradients seldom exceeded 1 ‰, with highest values toward the south. Thus they are indicative of the mixing of bay and gulf waters. On two occasions reversed linear gradients were recorded (Table 1, January 7 and March 9, 1960). These data are difficult to interpret since on both occasions the longshore currents were directed southward. Salinity gradients were not encountered during the months of June, July, August, September, October, and November, with the exception of 6 collections: 2 in October 1959, 1 in November 1959, 1 in July 1960, and 2 in September 1960. Intermixing of bay and gulf waters on the open beach south of Aransas Pass Channel, as judged from salinities, occurs in late winter and spring, with only sporadic mixing at other times of the year.

The over-all seasonal change in salinity (Fig. 2) shows a steady climb to high values beginning in May and probably reflects the high rate of evaporation which occurs during summer. The abrupt decline of salinities during September can be related to heavy rains and run-off which occurred during late summer and fall. The lowest salinities were re-

corded in January, March and April and, as indicated by Gunter (1958), can be correlated also with increased rainfall and run-off.

Seasonal Temperature Patterns

Mean water temperatures for the 10 sampling stations along the beach do not show such abrupt changes during the year when compared to changes in salinity (Fig. 2). Temperature of the water in the surfzone parallels seasonal changes in insolation, but also is directly affected by ambient air temperatures. As Gunter (1958) indicated for this beach, water temperatures lag behind changes in ambient air temperatures, particularly during periods of abrupt weather changes. Lowest temperatures were encountered during January and February and correlate with the passage of strong cold fronts from the north.

Longshore temperature gradients were not well developed (Table 1). When they did occur, differences did not exceed 1°C and were as often oriented up the beach as down the beach with no apparent seasonal pattern (e.g., January 7 and January 20, 1960; August 8 and August 17, 1960).

Seasonal Planktonic Respiration and Photosynthesis

METHOD

Estimation of planktonic metabolism has been measured most often by a light-dark bottle method (Gaarder and Gran, 1927) wherein changes in the oxygen content of water with time are used as a basis for calculation of respiration and photosynthetic rates. Although the method has inherent disadvantages (Steeman-Nielsen, 1952; Ryther and Vaccaro, 1954; Vacarro and Ryther, 1954; and Ryther, 1956), its simplicity lends the technique to quick estimation of planktonic metabolism for most waters. Two major objections are: (1) that enclosure of plankton in a bottle may affect metabolism and (2) that the surface of the bottles provides an enlarged area for bacterial proliferation which may affect oxygen levels. Short term sampling experiments by Ragotzkie (1959), however, indicated that respiration of plankton from estuarine waters in dark bottles was constant over a 36-hour period and suggest that enclosure of plankton, at least for short periods, should not seriously bias resulting estimates of metabolism.

Estimation of plankton production in the surfzone water along Mustang Island beach required minor modification of the light-dark bottle method. The constant agitation of the water and its contained plankton by wave action suggested that agitation of the sample bottles would provide more realistic results. To accomplish simulated surf motion in the samples, a bottle holder was constructed which accommodated 3 dark bottles and 3 light bottles (Fig. 3). Buoyancy and stability were provided by 4 steel crossarms which were directed upward at a 45° angle from the wood bottom. Floats at the tips of the crossarms were adjusted in size until the device had positive buoyancy. The entire apparatus was positioned in the water at an appropriate depth by tying it to a Danforth anchor. Tidal fluctuations varied from about one to one and one-half feet. Depth of the bottle holder was adjusted so the light bottles were approximately six inches beneath the surface during low tide. The apparatus rocked shoreward as each wave passed and seaward with outgoing water movements. As a result, agitation of the plankton enclosed in the bottles was proportional to surf action on any given sampling day.

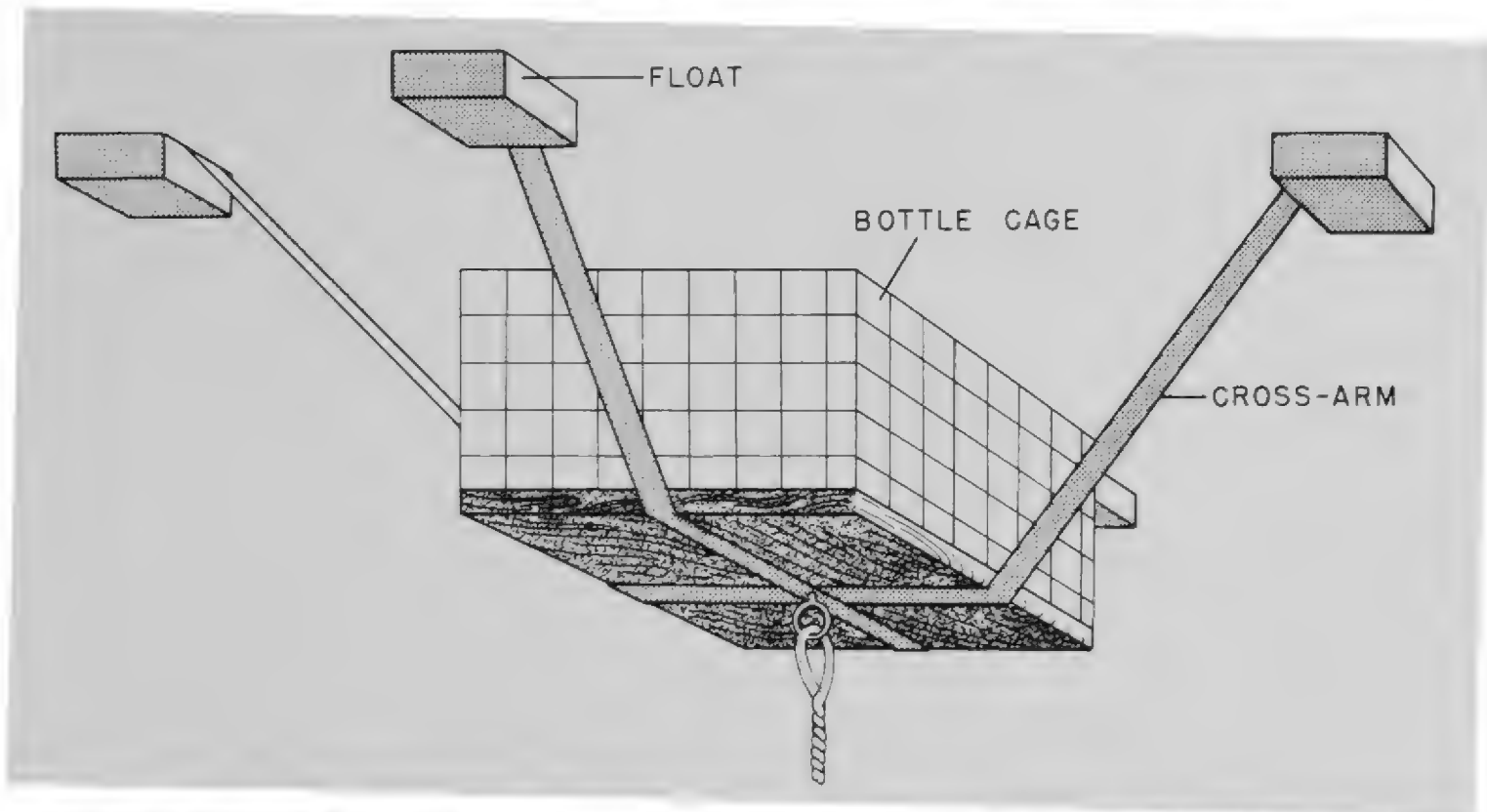


FIG. 3. Light-dark bottle holder used to simulate surf motion. The rope is tied to a sand anchor. Water motion rocks the cage to and fro in proportion to wave action. Floats buoy the apparatus and orient the light bottles at the top of the cage toward the surface.

Dissolved oxygen was measured by the Pomeroy-Kirschman sodium azide modification of the Winkler method (Faber, *et al.* 1955). Sample bottles were 125 ml capacity. Throughout the entire period sampling was begun between 1100 and 1300 and ended at the same time on the following day. Results for the year of sampling are recorded in Table 2.

Data represent samples collected from the first longshore trough between stations 3 and 4, lying 2 to 3 miles south of Caldwell Pier, Port Aransas. Initial oxygen samples and the dark and light bottles were filled by siphoning from a 5-gallon glass vessel after the water had been stirred and allowed to stand for 5 minutes. In spite of the attempt to equalize oxygen values at the start, considerable variation occurred on occasion (see confidence intervals for start bottles, Table 2). The mean coefficient of variance for titration of a constant standard was 0.96 per cent (7 triplicate subsamples of saturated distilled water), whereas the mean coefficients of variance for initial oxygen, light bottle, and dark bottle samples were 2.17, 2.19 and 1.51 per cent respectively. Variance for field data was approximately twice the titration error of about 1 per cent.

RESPIRATION

Seasonal changes in plankton respiration and photosynthesis appear to follow a distinct pattern (Fig. 4). Respiration (R) maintained a low level from late November through mid-March and April. Bursts of high respiration occurred during late March and the month of May. High spring respiration can be correlated with the initial rise in water temperature from the low temperatures of January–February. However, examination of the seasonal salinity curves indicate that the high respiration during March and May is correlated with sudden large increases in salinity of the beach water (Fig. 2). The increased salinity can be attributed in part to the influx of gulf water on the beach resulting from prevailing wind direction (see Fig. 2 and Table 1). This suggests that high respira-

TABLE 2

Seasonal oxygen values for start bottles and 24-hour dark and light bottles from samplings of the surf water at Mustang Island, Texas
Data represent mean oxygen values and the 95% confidence limits expressed in mg oxygen per liter.

Date of sampling	Start bottles mean $\pm$ 95% CI		Dark bottles mean $\pm$ 95% CI		Light bottles mean $\pm$ 95% CI	
Oct. 13, 1959	7.30	0.30	6.36*	0.17	7.53	0.34
Oct. 23, 1959	8.57	0.11	6.66*	1.03	8.79	0.22
Nov. 3, 1959	8.39	0.26	7.30*	0.52	8.76	0.30
Nov. 12, 1959	8.54	0.60	7.77	0.26	8.38	0.13
Nov. 19, 1959	9.27	0.22	8.89*	0.11	9.62	0.30
Nov. 23, 1959	8.57	0.17	8.38	0.39	9.03*	0.22
Dec. 2, 1959	7.82	0.22	7.35	0.26	8.57*	0.13
Dec. 8, 1959	8.08	0.22	7.83	0.26	8.55*	0.31
Dec. 18, 1959	8.72	0.11	8.41*	0.11	9.59*	0.46
Jan. 7, 1960	9.57	0.51	9.40	0.09	9.24	0.52
Feb. 18, 1960	7.34	0.06	7.07*	0.19	7.52	0.52
Mar. 2, 1960	8.83	0.19	8.68	0.13	9.23	0.56
Mar. 16, 1960	9.28	0.19	9.06	0.09	9.26	0.56
Mar. 30, 1960	10.50	0.25	8.09*	0.04	9.76*	0.43
Apr. 13, 1960	7.66	0.11	7.49	0.13	8.04*	0.22
Apr. 27, 1960	7.21	0.25	6.95	0.17	7.50	0.52
May 12, 1960	10.00	0.06	7.67*	0.99	9.69	1.25
May 31, 1960	9.12	0.53	5.79*	0.22	6.56*	0.60
June 16, 1960	7.03	0.13	6.51*	0.04	7.51	0.39
July 1, 1960	7.22	0.06	6.43*	0.22	7.95*	0.52
July 16, 1960	6.41	0.36	4.91*	0.30	7.63*	0.43
July 29, 1960	7.16	0.30	6.40*	0.09	8.59*	0.86
Aug. 17, 1960	8.71	0.31	6.73*	0.09	7.80*	0.34
Sept. 6, 1960	9.83	0.45	8.81*	0.22	11.32*	0.56
Sept. 20, 1960	9.84	0.45	8.68*	0.43	13.03*	0.65
Oct. 6, 1960	10.50	0.64	9.59*	0.17	12.21*	0.69
Oct. 24, 1960	10.68	0.21	9.42*	0.90	13.29*	1.56

*—Difference from start bottle 95% CI significant.

tion during spring is related to spring pulses and breeding of gulf plankton, rather than to an effect of plankton from the large Texas bay systems.

Inclusion of summer and late fall respiration values for June through mid-November yields a mean summer-fall respiration of $1.05 \text{ g O}_2/\text{m}^3$ per day ($\text{SE} = \pm 0.005 \text{ g}$). Excluding the high spring respiration, similar treatment of data for late fall through spring yields a mean respiration of $0.26 \text{ g O}_2/\text{m}^3$ per day ($\text{SE} = \pm 0.007 \text{ g}$). Thus, on the average, summer-fall respiration exceeded winter respiration by a factor of four (Student's $-t = 34.0$, where $t_{(.995)} = 2.65$).

PHOTOSYNTHESIS

Net photosynthesis (P_n) varied throughout the year, but tended to be low in the late fall of 1959 and the winter-spring period of 1960, and was highest during the summer and early fall of 1960 (Fig. 4). Of the total of 27 light bottle samples for net photosynthesis, 15 are significantly different from the initial oxygen samples (Table 2). The net photosynthesis values for October 1959 are quite low compared to similar values for October 1960 and indicate high variability from year to year.

Combination of the summer and early fall net photosynthetic rates gives a mean summer-fall P_n of $0.99 \text{ g O}_2/\text{m}^3$ per day ($\text{SE} = \pm 0.039 \text{ g}$). Similar treatment of the late fall, winter, and spring values yields a mean P_n of $0.36 \text{ g O}_2/\text{m}^3$ per day ($\text{SE} = \pm 0.004$

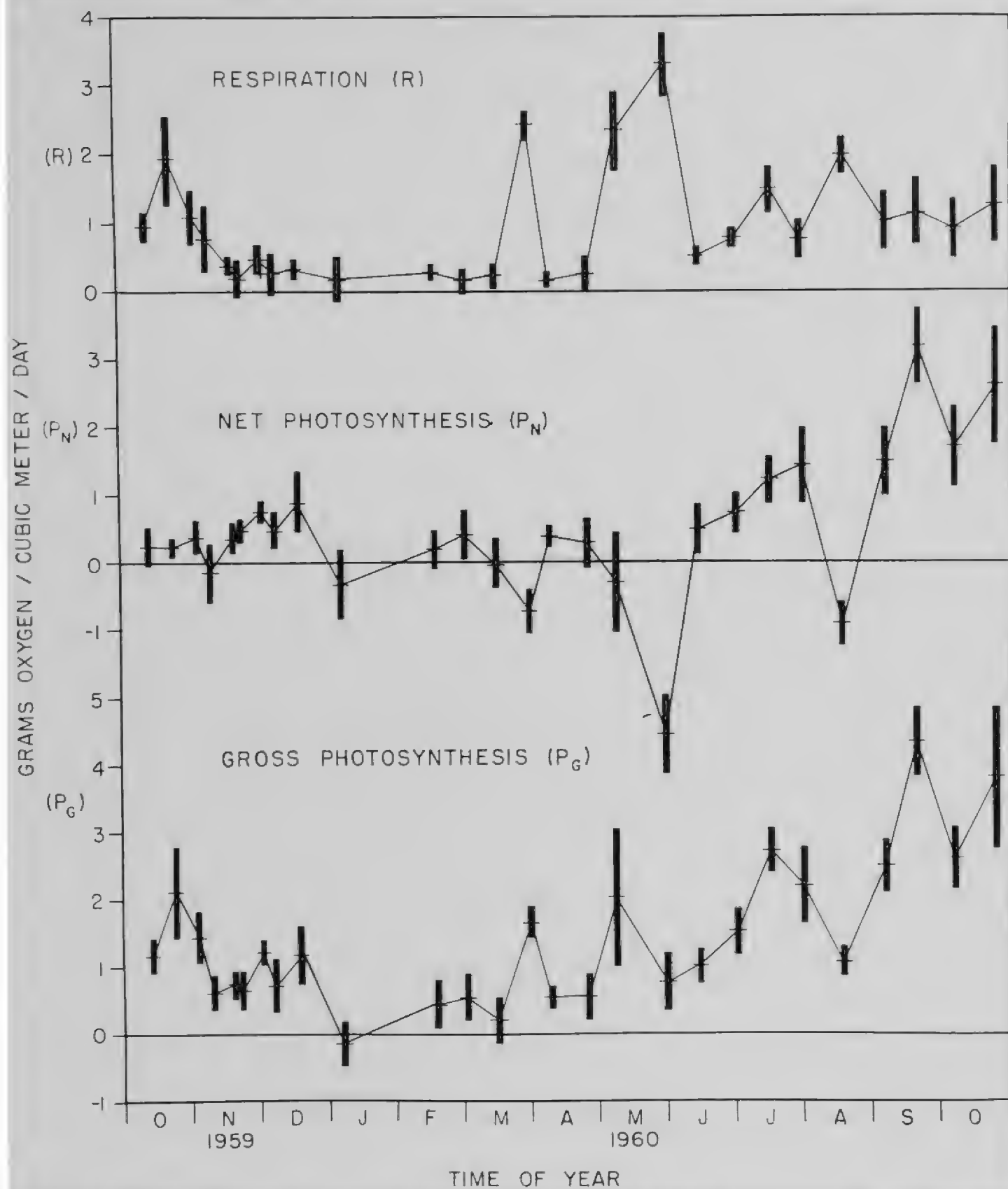


FIG. 4. Seasonal plankton production in the surf south of Port Aransas, Mustang Island, Texas, as obtained by the light-dark bottle method. Solid vertical bars represent the 95% confidence intervals of the means, which are represented by the thin horizontal lines. Raw data are presented in Table 2.

g). Summer-fall net photosynthetic rates exceeded the winter-spring rates by a factor of 2.75 (Student's $t = 16.14$, where $t_{(.995)} = 2.65$).

Associated with the high respiration rates during spring months and the highest summer rate are corresponding low photosynthetic rates that are insufficient to balance the respiration of the plankton. On a few occasions, P_n was negative during winter months (Fig. 4). Seasonal gross photosynthesis (P_g), the algebraic sum of R and P_n , approached a maximum in the late summer and early fall of 1960.

OXYGEN LEVELS IN THE SURFZONE

Oxygen saturation values reveal that the surf water is most often supersaturated with oxygen or close to the 100% saturation level (Fig. 5); the values represent only the time period between 1100–1300 hours and it is not known if supersaturation declines during the night. Interestingly, the highest degree of supersaturation (about 170%) occurred in late summer and early fall of 1960, the seasonal periods when temperatures and salinities were at a maximum (Table 1; Fig. 2). The high summer supersaturation of the water with oxygen can be correlated with the high rates of net photosynthesis that occurred during this period (Fig. 4), but the peaks associated with March and May are more difficult to equate. The latter coincided with high rates of respiration for March and May, but since net photosynthesis was negative during this time undersaturation or, more likely, saturation of the water with respect to oxygen would seem more probable. Because the spring season is associated with major changes in the direction of prevailing winds and the associated influx of gulf water on the beach, and the general increase in temperature and salinity, these supersaturation peaks may be the result of physical processes. Alternatively, the high oxygen levels may result from photosynthetic activity of plankton in open gulf water before the water reaches the beach. This alternative would necessitate either a destruction of phytoplankton or a depression of photosynthesis in the surf environment since P_n was low (Fig. 4). Unfortunately, the cause of spring super-

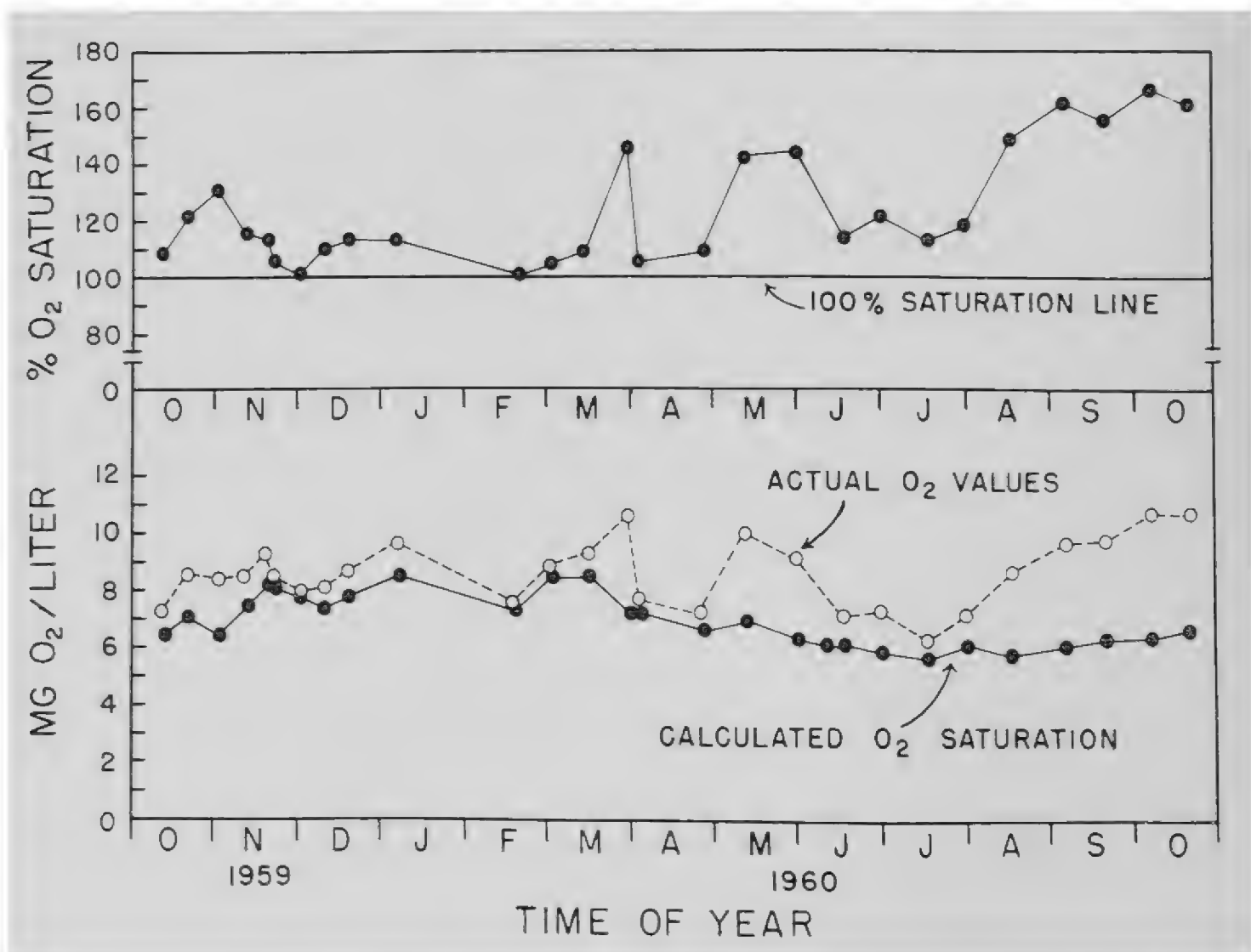


FIG. 5. Seasonal changes in the oxygen content of the surf south of Port Aransas, Mustang Island, Texas. The high degree of supersaturation during summer and fall coincides with high net plankton photosynthesis in the surf. The supersaturation peaks in spring coincide with negligible or negative net photosynthesis and remain unexplained.

saturation is obscure. The high summer oxygen levels most probably result from the high net photosynthesis determined for the period. Large concentrations of the blue green alga, *Trichodesmium*, were observed throughout this period and correlate with the high net photosynthesis.

Net Plankton Abundance

A total of 14 plankton hauls were made from March 9, 1960 through October 19, 1960. Identifications were made only to generalized types, and the number of specimens per cubic meter of water were calculated. Since the data are scanty, little can be said about absolute numbers of net plankton present. However, the data do reveal gross seasonal fluctuations in abundance and types, Table 3).

The largest total number of net plankton per cubic meter of water occurred in March, with lesser numbers present throughout the summer. Counts for September and October showed increases, but not to the levels of abundance attained during March (Table 3).

The March peak is associated with large numbers of crab and shrimp larvae, which become less abundant in summer. The bulk of the April, May, and June populations is comprised of copepods. July and August are characterized by the virtual absence of net plankton from the surf. During this period water clarity is at a maximum. The September and October peaks are caused primarily by copepods, with both mysids and chaetognaths relatively abundant. Over-all, there appears to be a shift from a spring, decapod larval type plankton to a copepod plankton. In late summer and early fall, this copepod abundance increases along with mysids and chaetognaths. Unfortunately, winter samples are not available.

Discussion

The foremost results of the study are the seasonal fluctuations of variables wherein biological factors, represented by plankton metabolism, reach their highest levels in summer and their lowest levels in winter. Other studies on the biota of the beach at Mustang Island show similar fluctuations. The abundance of fishes on the Mustang Island beach also varies seasonally (Gunter, 1958; McFarland, 1963); the greatest abundance of fishes occurs in summer, declines in late summer and fall, and is lowest during late fall and winter. Loesch (1957) reported that *Donax* reached its greatest abundance on the beach during June and then declined gradually until fall.

The abundance of both fishes and infauna (primarily *Donax*) on the Mustang Island beach is considerable, at least, through the summer. Certainly *Donax* and, to a degree, many of the fishes, such as the genera *Harengula*, *Anchoa*, *Brevoortia* and *Mugil*, must depend on plankton for food. Whether the availability of plankton is sufficient to meet their dietary needs is quantitatively unanswerable at this time. The correlation of plankton metabolism peaks (P_g) with the greatest abundance of fishes and *Donax* suggest that plankton serve as a primary food source to the higher trophic levels.

The average values for both summer-fall and winter-spring respiration and photosynthesis indicate that photosynthesis is usually in excess ($P_g/R = 2.0$). The average summer-fall value for respiration ($R = 1.05 \text{ g O}_2/\text{m}^3 \text{ per day}$) and net photosynthesis ($P_n = 0.99 \text{ g O}_2/\text{m}^3 \text{ per day}$) are somewhat lower than a July 1957 value reported for

TABLE 3

Seasonal changes in net plankton during, spring, summer and the fall of 1960. Nonbracketed values are the average numbers of individuals per cubic meter of water. Bracketed values are the ranges for replicate samples. Each mean represents 4 samples. The sample for August 17, 1960 represents only 2 samples.

General type of animal	Date, 1960													
	Mar. 9	Mar. 16	Mar. 23	Apr. 13	May 13	May 31	June 17	July 16	July 29	Aug. 17	Sept. 6	Sept. 20	Oct. 6	Oct. 19
Comb jellies	0.3 (0-1.0)	0.2 (0-0.6)	---	---	---	---	---	---	1.9 (0-3.9)	---	---	---	---	---
Veliger larvae	---	---	---	---	1.0 (0-2.1)	---	---	---	---	---	---	---	---	0.3 (0-0.9)
Bryozoa	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Chaetognatha	---	---	---	---	---	---	---	---	---	---	---	---	3.6 (2.8-4.1)	16.3 (9.4-27.3)
Mysids	---	---	---	0.2 (0-0.8)	0.8 (0-2.1)	---	---	---	---	---	1.3 (1.0-1.5)	5.0 (3.1-6.4)	---	---
Isopods	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Amphipods	---	---	---	---	0.7 (0-2.8)	9.8 (9.5-16.6)	---	---	---	---	---	---	---	---
Copepods	1.2 (0-4.0)	---	---	19.7 (1.3-42.1)	15.7 (8.6-26.9)	3.9 (2.3-6.6)	7.8 (0.5-8.0)	---	---	0.7 (0.5-0.8)	0.3 (0-1.0)	41.3 (27.0-67.0)	5.5 (2.8-7.6)	34.0 (25.5-38.7)
Shrimp larvae	4.2 (2.2-7.7)	5.9 (0-13.0)	---	---	---	---	2.1 (0.8-3.6)	---	0.2 (0-0.5)	---	1.3 (0-4.0)	---	---	---
Crab larvae	79.1 (34.0-129.4)	146.5 (19-326.0)	5.9 (1.4-12.5)	0.4 (0-0.7)	0.9 (0-2.3)	---	0.1 (0-0.4)	---	---	---	0.9 (0-2.0)	---	---	---
Fish larvae	33.2 (7.4-97.0)	4.5 (0.4-9.8)	---	2.6 (0-3.9)	---	---	---	---	---	---	---	---	---	0.3 (0-1.0)
Totals	118.0	157.1	5.9	22.9	19.1	13.7	10.0	0.0	2.1	0.7	3.8	46.3	9.1	60.6

the gulf shelf off the beach, but are close to average values for a variety of Texas bays (Odum and Hoskins, 1958).

Seasonal measurements of primary and gross production of plankton by the light-dark bottle method for the Gulf of Mexico and South Atlantic areas are limited mainly to the work of Odum and Hoskins (1958) for Texas bays and, of Ragotzkie (1959) for estuaries in Georgia. The gross photosynthesis and respiration curves for the Upper Laguna Madre and Baffin Bay, Texas, show higher values during summer, but seasonal changes were virtually absent in Redfish Bay, Texas (Odum and Hoskins, 1958). Ragotzkie's results, which represent more samples, show definite increases of plankton respiration in both spring and summer, whereas net photosynthesis tended to be negative in summer.

The low yields of net plankton obtained during the summer months, as compared to the spring and fall, indicate that nanoplankton may be responsible for the greater bulk of summer respiration. The high net photosynthesis of late summer and fall suggest that phytoplankton constitute a major source of organic matter for higher trophic levels. However, until studies that correlate phytoplankton counts with primary production are undertaken this suggestion must remain speculative. The results of Rodhe et al. (1958) for primary production in Swedish lakes indicate, however, a dominance of nanoplankton in total production. The present results indicate that a net production of organic matter does occur in the plankton during the summer. Therefore, the potential exists that net production may be capable of sustaining the beach populations throughout the summer. However, the high respiration of plankton in spring and summer suggests that organic matter is probably imported to the beach in considerable quantities. The importation rates for plankton were not measured, but judging from the strong longshore currents a tremendous bulk of plankton must traverse the beach each day. As a result the higher trophic levels of the beach community probably utilize only a small fraction of the available plankton.

Summary

(1) Seasonal changes in temperature and salinity along a 10-mile stretch of open Gulf of Mexico beach on Mustang Island, Texas, are reported for October 1959 through October 1960. Results reveal a gradual change in temperature from low values of 12–13°C in mid-winter to high values of 33–34°C during summer. Salinity follows the same seasonal pattern, but is more variable, particularly during spring months.

(2) Measurements of plankton respiration in dark bottles indicate that highest rates occur during spring when crab and shrimp larvae are abundant. The average summer respiration value of 1.05 g O₂/m³/day exceeds the average winter value by a factor of four. Net photosynthesis is variable throughout the year, but reaches its peak during summer and fall. Net photosynthesis equaled respiration in both summer and winter. With the exception of spring respiration bursts, usually a positive net production occurred in the plankton communities swept over the beach.

(3) The seasonal maximal plankton metabolism coincides with the abundance of higher trophic levels of the beach environment, and this relation indicates that the importation of plankton as a result of seasonal factors is synchronized with the seasonal energy requirements of the beach communities.

Acknowledgments

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Seasonal Change in the Number and the Biomass of Fishes from the Surf at Mustang Island, Texas¹

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Abstract

During 1960 and 1961 the numbers and biomass of fishes in the surf at Mustang Island, Texas were measured seasonally by seining procedures. A total of 47 species of fish were captured and are classed as all-year, spring-summer, summer, and winter-spring residents, or, as sporadic occurrences. During winter, on the average only four species were captured from the surf. Species captured increased to an average of 16 during summer. Biomass of fishes increased from a winter mean of 25.8 pounds to a summer mean of 103.2 pounds of fish per surface acre of surf. *Mugil cephalus* was the most common fish and constituted 46% of the total weight of fish captured.

The available data on seasonal abundance suggests that the most abundant species, or their ecologic counterparts, are represented heavily in the beach fish fauna from year to year. The most abundant species either are or tend to be predominantly plankton feeders. Estimation of the assimilation and importation of organic carbon to the beach, in the form of plankton, indicate that it is more than sufficient to sustain the fish population during summer. It is concluded that the beach fauna of the Texas coast is largely dependent on plankton for its existence.

Introduction

The paucity of information concerning vertebrates characteristically associated with outer coastal beach environments has been pointed out by Gunter (1958). Fishes from beaches in the vicinity of Beaufort, North Carolina were reported by Pearse, Humm and Wharton (1942) while the vertebrates on the outer beach at Mustang Island, Texas, have been reported by Gunter (1945 and 1958). These studies indicate the seasonal fluctuations in the fish faunas of sub-temperate beach environments, wherein the populations decline both in total numbers of fish and in species composition during winter. The results reveal that from 60 to 80 per cent of the fish fauna of the south Atlantic and Texas beaches is composed of but a few species. Seasonal sampling of fishes from an open coast beach near Saint Petersburg, Florida indicate that close similarities in species composition and relative abundance exist with the fish fauna of the Texas coast (Springer and Woodburn, 1960). Dissimilarities appear mainly in the replacement of temperate species with tropical relatives.

No data appear to be available on the biomass of fishes characteristic of these beaches. In this paper the species composition, numbers of individuals and the biomass of fishes are reported for the period May 1960 through July 1961. The environment sampled, at Mustang Island, Texas, is the same outer coast beach studied by Gunter (1945 and

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1958). The information that has accrued on this stretch of coastline, therefore, makes it one of the better known beaches of North America.

Materials and Methods

EQUIPMENT

Estimation of the biomass of fishes from May 1960 through July 1961 was obtained by rapidly setting a large beach seine over a specified area of the surf fringe. The net measured 633 feet in length and was designed to lay into the beach profile. The beach profile in the area of the study maintains a relative constancy throughout the year (Hedgpeth, 1957; McFarland, 1963). As a result the wings of the net were tapered from two feet deep at the ends to ten feet deep where the wings joined the cross piece (relaxed webbing measurements). Webbing was number 9 Nyak twine woven to $\frac{3}{4}$ inch stretch size ($\frac{3}{8}$ inch bar). Plastic three-inch floats were placed one foot apart along the float line. Because of the strong wave action often encountered, heavy floating was required.

The lead line consisted of 633 feet of galvanized link chain weighing one-half pound to the foot. Examination of lead line action by diving indicated that the bottom of the net remained on the sand bottom both on the longshore bars and in the troughs. Escape-ment of fish beneath the lead line, if it occurred, probably took place only when the lead line was pulled over small holes.

Specific dimensions of the net were: wings, each 200 feet long; cross piece, 185 feet long; bag, 48 feet wide, throat size, 25 feet wide by 8 feet deep, depth of sock 25 feet. The bag was placed in a corner between the cross piece and one of the wings. Because of the longshore currents the bag was set downstream so that it would open into the net. After initial test hauls the depth of the sock was reduced to ten feet to lessen downstream drag on the net.

The net was set from an 18 foot surf skiff in which the net was stacked flat in a well located midships. The net was payed over the helmsman's head *via* a rack located above the transom. Early attempts to lay the net from a roped condition led to twisting. Addition of the overhead rack eliminated net twisting and further avoided entanglement of the net with the outboard motor. The entire rig was capable of being propelled in one foot of water, the draft being about 6 to 7 inches loaded and only 3 to 4 inches empty.

METHOD OF SETTING THE NET

Theoretically an ideal set of the net would cover a rectangular area with the long dimension perpendicular to the surf fringe (224 feet) and the short dimension parallel to the beach (185 feet). The cross piece, thus, usually lay in water of the second longshore trough at a depth of 6 to 8 feet. The surface area of water enclosed under ideal conditions represented 0.951 surface acre and about 4,550 cubic meters volume. Because of strong longshore currents this ideal was seldom achieved. More often the outward course of the skiff was at a slight angle in the direction of the longshore current. In addition, a degree of net drift occurred before the entire net was payed out. As a result the acreage of water surface covered most often exceeded 0.951 acre.

To account for this deviation, at each sampling, a distance of 185 feet was marked out along the beach. The corners of the wings and cross piece of the net were marked with white floats and changes in course were always made at these positions. An individual,

onshore, paced off course changes from the marker posts and transcribed these to a board marked with the ideal course. As a result, with the known dimensions of the net and the measured deviation from the theoretical course the actual area enclosed could be calculated. For the 25 samplings reported in this paper the average area covered was 1.10 acres.

A set, from start to enclosure of the area, normally took less than two minutes. Once set, the net was hauled immediately upon the beach by pulling first on the upstream wing and crosspiece. A slight pull was maintained on the downstream wing to keep the bag opened into the current. The net was pulled with seine lines snapped to the lead line and attached to two trucks. Inward surf action and the longshore current assisted in relieving tension on the net. The net was beached within ten minutes or less in all samplings.

ESCAPEMENT

The effectiveness of the chain in reducing escapement of fishes beneath the lead line has been indicated. On several occasions when setting the net the closing wing was terminated 50 to 60 feet out from the beach and provided a route of escape for fishes. However, the presence of a seine line, the fact that the water in this location was only about one foot deep, and the rapid closure of the area from hauling of the net are believed to have cut off escapement. At no time were fishes observed to use this escape route.

Escapement over the float line occurred with two species of fish, i.e., *Mugil cephalus* and *Trachinotus carolinus*. This occurred on three occasions and seems unusually low since both species are predilected toward jumping. Losses were accounted for by recording the number of fish that jumped the net. The number that escaped were added to the actual catch and their weight estimated by sampling members of the species actually caught.

Escapement through the mesh of the net occurred with very small fishes. Specific losses depended upon the species and their respective abilities to swim through the $\frac{3}{8}$ inch bar mesh. On several occasions a small fine mesh net was used to surround the bag of the larger net prior to its being hauled from the surf. Fishes which escaped from the larger net under these conditions seldom exceeded 40 mm and more often were under 30 mm in standard length. As a result, all data in this report ignore fish populations in the surf under 40 mm in standard length. This is regrettable, but the extreme size of the net precluded the use of a finer mesh size because the increased drag resistance and the strong longshore currents would have made the net unmanageable. In addition, a smaller mesh size would have seriously reduced the strength of the net.

All fish collected were identified to species with the exception of the genus *Anchoa* and the filefish taken on one occasion. Specimens were weighed individually, but where the number of specimens of a species were large, series of sub-samples containing 20 individuals were weighed at random and the total numbers and weight calculated. The actual catch and the estimated area covered during each sampling were corrected to a one-acre basis. All values reported, thus, represent numbers or pounds of fish per acre.

Types and Numbers of Fishes Caught

A total of 47 species of fish were caught during the sampling year. The species caught

and the numbers of each species per acre for each sampling are compiled in Table 1. During the winter months the total number of species represented in the collections ranged from a low of two to a high of eight and averaged four. During the rest of the year the number of species ranged from 11 to 21 and averaged 16.

On a few occasions considerable numbers of one species were seined. The most exceptional example was the capture on March 1, 1961, of 35,881 specimens per acre of the marine catfish, *Galeichthys felis*. Throughout the rest of the year this species was represented in individual catches by less than 104 specimens per acre. The high numbers are believed to reflect a breeding movement or aggregation of the populations shoreward. That this movement was general was demonstrated by the capture of large numbers of this species with a smaller net during the afternoon and evening of March 1, 1961. Similarly, large numbers of the striped mullet, *Mugil cephalus* were taken on December 15, 1960. This is not unusual at this time of year since the species is known to migrate from the Texas bays in large schools during the fall. Another example of unusually large numbers of a species was encountered on May 26, 1961, when the haemulid, *Conodon nobilis*, was taken in the surf. At no time in the author's experience had this species been taken from the beach, although it is common in trawl hauls from deeper water off of the beach. Gunter (1945 and 1958) does not report *C. nobilis* from the surf. Examination revealed that the gonads of many specimens were ripe, but whether the presence of *Conodon* on the beach represents a breeding movement remains conjecture.

The average total number of fish captured per acre during winter was 82 and ranged from 16 to 151 specimens, whereas during spring and summer the average increased to 1,143 fish per acre and ranged from 290 to 2,830. In establishing these estimates, the unusual abundance of catfish on March 1, 1961, has been ignored.

Biomass of Fishes

For each species, the weight per acre for each sampling and the total weight of fishes per acre are given in Table 2. Total biomass of fishes during the various seasons is shown in Fig. 1. An increase in biomass from the winter lows to the spring-summer highs is evident, although considerable variation occurs from sample to sample. Average total biomass for the winter months, when the species composition of the catch was lowest, was 25.8 pounds per acre (the catches of December 15, 1960 and of March 1, 1961, when high numbers of mullet and catfish were taken have been ignored), and ranged from a low of 5.3 pounds to a high of 48 pounds per acre. During the spring-summer samplings the total catch ranged from a low of 32.5 pounds to a high of 271.8 pounds per acre with a mean of 103.2 pounds. Thus, weight of fish per acre increases fourfold from winter to summer. The number of species represented also increased fourfold for the same periods. However, the average increase in the total number of fishes for this period was fourteenfold and reflects the recruitment of smaller fish, as well as smaller species, into the beach populations during the spring-summer period.

Seasonal Characteristics of Fish Populations

The primary characteristic of the fish populations is the seasonal change in abundance. An identical result stems from the work of Gunter (1958) for the same beach environ-

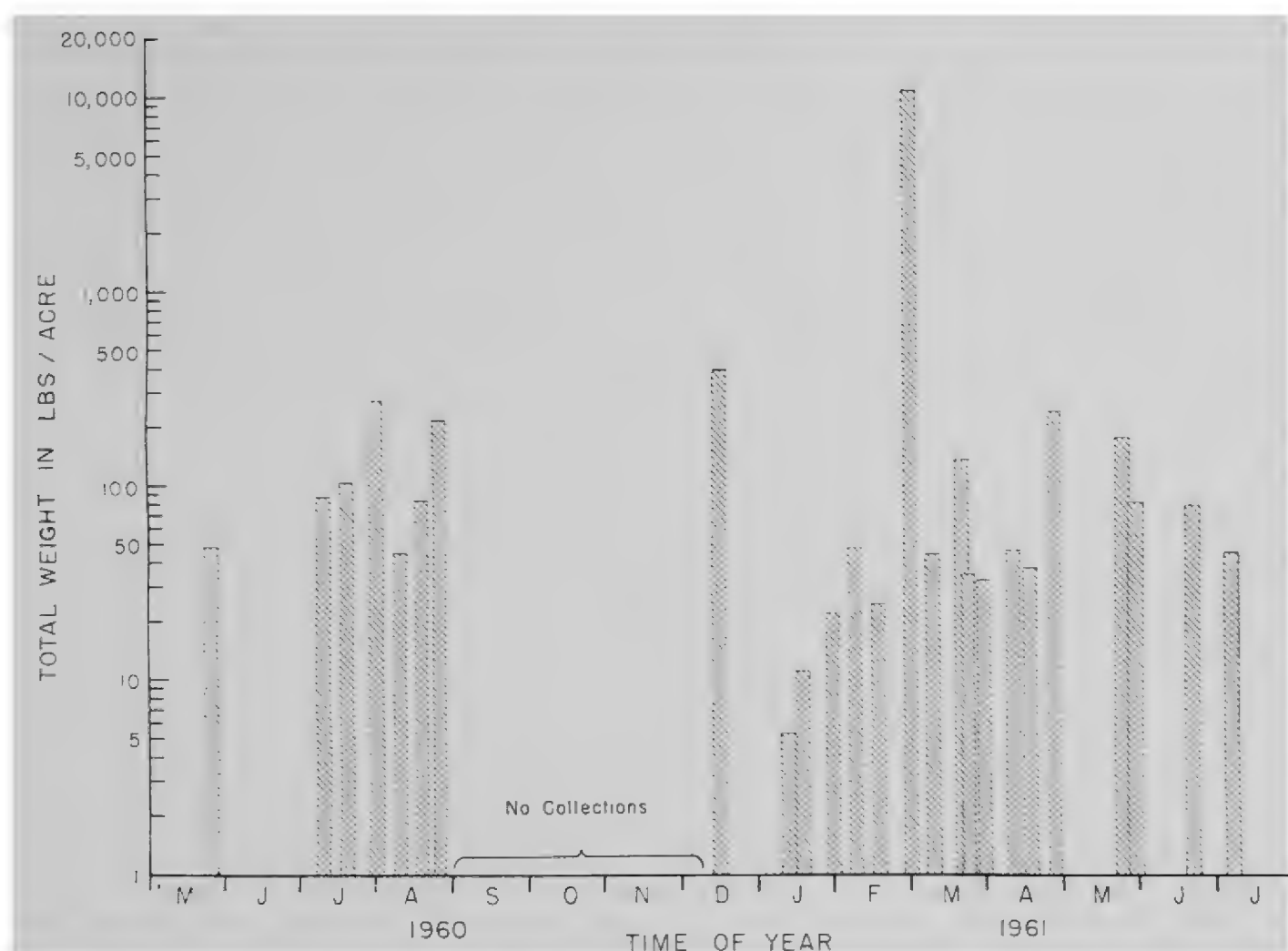


FIG. 1. Biomass of fishes in pounds per acre in the surf fringe at Mustang Island, Texas. The high values for December 15, 1960 and for March 1, 1961, represent mostly specimens of *Mugil cephalus* and *Galeichthys felis*, respectively.

ment. In addition to the seasonal changes, the results indicate the tendencies for some of the species to be present through more of the seasons than other species. In general, the 47 species of fishes collected through the year can be classified as: (1) All year residents; (2) Spring-summer residents; (3) Summer residents; (4) Winter-spring residents; and (5) Sporadics.

ALL YEAR RESIDENTS

Of the 47 species, three were captured throughout the year. The striped mullet, *Mugil cephalus* was present in all collections and usually represented 10% or more of the catch. Both *Galeichthys felis* and *Lagodon rhomboides* were caught throughout the year, although they were not taken during occasional hauls (see Tables 1 and 2). Neither of these fishes were as abundant as *M. cephalus* and, with the exception of the abundance of *G. felis* for the February 17 and March 1, 1961, collections, they normally represented something less than 5% of the catch.

SPRING-SUMMER RESIDENTS

During the spring and into the summer a variety of fishes entered the beach populations as sub-adults and increased in size throughout the summer. The pompano, *Trachinotus carolinus* is an exception. This species first appeared during March and was represented only by large adults. By the end of March large fish were no longer taken. Throughout the summer sub-adult pompanos increasingly entered the catches. The

TABLE 1

Total numbers per acre of each species and of all species at various dates through the years of 1960 and 1961.

Species	Date of Collection																									
	May 25	July 12	July 19	July 29	Aug. 10	Aug. 18	Aug. 26	Dec. 15	Jan. 13	Jan. 18	Jan. 31	Feb. 9	Feb. 17	Mar. 1	Mar. 10	Mar. 20	Mar. 24	Mar. 29	Apr. 11	Apr. 18	Apr. 28	May 26	May 31	June 22	July 7	
<i>Scoliodon terranovae</i>	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1	---	8	---	
<i>Sphyrna tiburo</i>	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	4	---	
<i>Narcine braziliensis</i>	1	1	---	1	---	2	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Dasyatis americana</i>	---	---	---	---	---	---	9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Dasyatis sabina</i>	1	1	3	---	15	39	90	---	---	---	---	---	---	---	---	---	---	1	---	14	18	13	---	41	20	
<i>Rhinoptera bonasus</i>	---	---	---	---	---	8	8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Elops saurus</i>	4	---	4	8	1	5	3	---	---	---	---	6	---	---	---	---	---	---	---	---	---	7	---	1	---	
<i>Harengula pensacolae</i>	---	---	1	---	---	---	---	---	---	---	---	---	---	---	---	7	284	133	1	4	---	3	11	6	74	
<i>Brevoortia patronus</i>	2	19	1	---	---	2	9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Anchoa</i> sp.	---	---	---	---	---	---	---	---	---	---	---	3	---	---	8	9	148	32	167	9	---	---	---	16	---	
<i>Galeichthys felis</i>	7	19	---	---	19	24	60	38	1	10	---	9	104	a*	27	2	2	2	---	1	---	15	5	---	23	
<i>Strongylura marina</i>	---	1	1	---	---	1	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Syngnathus</i> sp.	---	---	---	---	---	---	---	---	---	---	---	---	6	---	---	---	1	---	1	1	2	---	---	---	---	
<i>Mugil cephalus</i>	20	93	13	75	17	4	345	480	7	15	45	72	4	8	9	3	32	60	99	7	605	25	16	10	19	
<i>Menidia beryllina</i>	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1919	---	---	132	99	205	---	---	5	---	
<i>Polydactylus octonemus</i>	277	1061	2503	2197	47	83	55	---	---	---	---	---	---	---	---	---	85	330	1118	275	---	143	1923	---	38	
<i>Centropomus undecimalis</i>	1	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1	---	---	---	---	
<i>Pomatomus saltatrix</i>	4	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	11	6	9	6	2	---	
<i>Elagatis bipinnulatus</i>	---	---	---	---	---	3	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	
<i>Trachinotus carolinus</i>	124	55	40	---	34	23	62	---	---	---	---	---	---	4	14	68	2	---	---	1	13	---	5	57	42	
<i>Caranx bartholomaei</i>	---	1	---	49	---	---	---	---	---	5	---	---	---	---	1	---	---	---	---	---	---	---	---	---	---	
<i>Caranx hippos</i>	---	---	38	47	3	2	12	---	---	---	---	---	---	---	---	---	---	---	---	---	1	1	20	8	47	
<i>Chloroscombrus chrysurus</i>	8	---	---	---	3	---	---	---	---	---	---	---	---	---	---	---	1	---	---	---	31	220	780	20	5	
<i>Selene vomer</i>	2	---	---	---	2	---	1	---	---	---	---	---	---	---	---	---	---	---	---	---	1	2	---	---	---	

a* 35,881 catfish.

TABLE 1—Continued

Species	Date of Collection																								
	May 25	July 12	July 19	July 29	Aug. 10	Aug. 18	Aug. 26	Dec. 15	Jan. 13	Jan. 18	Jan. 31	Feb. 9	Feb. 17	Mar. 1	Mar. 10	Mar. 20	Mar. 24	Mar. 29	Apr. 11	Apr. 18	Apr. 28	May 26	May 31	June 22	July 7
Eucinostomus argenteus	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1
Conodon nobilis	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	429	----	----	15
Bairdiella chrysura	----	..	----	----	----	----	----	----	8	8	..	42	----	----	16	13	1	12	1	22	2	----	----	----	
Sciaenops ocellata	----	1	----	..	1	----	1	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	
Leiostomus xanthurus	75	----	10	26	42	27	57	----	----	----	----	----	----	----	----	26	----	----	----	----	----	10	----	----	
Micropogon undulatus	2	7	----	----	----	----	----	----	----	----	----	----	----	----	3	----	----	----	----	----	----	----	----	----	
Menticirrhus americanus	23	----	----	----	----	----	----	----	----	----	----	----	----	----	5	----	----	----	----	----	----	----	----	----	
Menticirrhus atlanticus	----	----	----	----	----	----	----	----	----	----	----	----	----	3	----	----	----	----	----	----	----	1	----	200	
Menticirrhus littoralis	----	36	136	154	247	54	401	..	----	----	----	----	8	----	----	11	16	31	10	25	77	40	25	111	77
Pogonias cromis	----	----	----	----	----	----	4	----	----	----	----	----	----	----	----	53	4	4	----	1	1	2	3	3	4
Cynoscion nebulosus	2	1	----	2	2	3	2	----	----	----	----	----	----	17	----	----	----	----	----	----	----	1	----	1	1
Lagodon rhomboides	3	39	----	5	5	----	2	2	----	----	26	10	----	----	1	59	1	4	9	7	13	91	25	2	28
Archosargus probatocephalus	----	----	3	2	3	6	2	----	----	3	----	----	----	----	1	1	1	1	----	2	7	----	----	6	3
Chaetodipterus faber	1	1	..	----	1	2	1	----	----	----	----	----	----	----	----	----	----	5	1	11	13	4	----	----	19
Trichiurus lepturus	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2	----	----	----	----	----
Scomberomerus maculatus	----	1	----	----	1	2	----	----	----	----	----	----	----	----	----	----	1	----	----	----	----	1	----	10	----
Peprilus paru	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	168	----	----	----	----	----
Paralichthys lethostigma	11	----	----	----	1	1	----	----	----	----	----	----	----	----	----	1	----	----	6	2	5	2	----	----	----
Filefish	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	3
Lactophrys tricornis	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1	----
Sphaeroides nephelus	----	----	----	----	----	----	----	25	----	3	----	----	----	----	2	----	----	2	----	----	----	----	----	----	----
Opsanus beta	----	----	----	----	----	----	----	----	----	----	----	8	----	----	----	----	----	----	----	----	----	----	----	----	----
Histrio histrio	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	11	----	----	----
Totals	568	1335	2754	2564	444	290	1126	547	16	44	71	151	122	35913	87	2172	579	617	538	662	1001	1020	2830	508	419

Seasonal Change of Fishes from the Surf at Mustang Island, Texas

TABLE 2

Total weight in pounds per acre of each species and of all species at various dates through the years of 1960 and 1961

Species	Date of Collection																								
	May 25	July 12	July 19	July 29	Aug. 10	Aug. 18	Aug. 26	Dec. 15	Jan. 13	Jan. 18	Jan. 31	Feb. 9	Feb. 17	Mar. 1	Mar. 10	Mar. 20	Mar. 24	Mar. 29	Apr. 11	Apr. 18	Apr. 28	May 26	May 31	June 22	July 7
<i>Scoliodon terranovae</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1.2	....	18.0	....
<i>Sphyrna tiburo</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	6.5	....
<i>Narcine braziliensis</i>	.6	....	....	0.8	....	1.3	.4	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Dasyatis americana</i>	....	....	....	....	....	....	5.8	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Dasyatis sabina</i>	.3	.3	1.4	....	1.9	12.0	16.1	....	....	....	....	....	....	....	....	....	....	.3	....	5.3	5.0	5.3	....	20.0	9.4
<i>Rhinoptera bonasus</i>	....	....	....	....	....	22.7	16.7	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Elops saurus</i>	2.1	....	1.4	6.6	.5	4.7	2.6	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2.3	....	.6	....
<i>Harengula pensacolae</i>	....	....	.1	....	....	....	....	....	....	....	....	2.6	....	....	....	.1	3.0	2.3	<.1	<.1	....	.2	1.6	.1	.9
<i>Brevoortia patronus</i>	.1	2.0	.1	....	....	.2	4.9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Anchoa sp.</i>	....	....	....	....	....	....	....	....	....	....	....	.1	....	....	.2	.1	2.7	.5	1.0	.1	....	....	....	.2	....
<i>Galeichthys felis</i>	.9	1.1	....	....	1.2	1.3	4.6	17.6	.2	.3	....	.1	20.6	a*	3.0	.1	.3	1.3	....	.1	....	2.3	1.2	....	1.4
<i>Strongylura marina</i>	....	.2	.2	....	....	.2	.1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Syngnathus sp.</i>	....	....	....	....	....	....	....	....	....	....	....	....	2.0	....	....	....	<.1	....	.2	.1	.2	....	....	....	....
<i>Mugil cephalus</i>	14.9	26.4	4.2	198.2	5.8	2.0	92.5	373.1	3.2	8.3	21.3	32.2	1.7	8.3	7.0	12.6	10.4	2.3	39.2	2.5	164.6	7.8	7.8	.4	7.5
<i>Menidia beryllina</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	33.1	....	....	1.7	2.5	2.7	....	....	.1	....
<i>Polydactylus octonemus</i>	1.2	37.7	59.4	28.0	2.1	2.4	3.9	....	....	....	....	....	....	....	....	....	.4	6.0	.7	4.1	....	3.1	21.9	....	1.7
<i>Centropomus undecimalis</i>	1.9	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	17.8	....	....	....	....
<i>Pomatomus saltatrix</i>	.2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1.0	.6	1.5	1.2	.4	....
<i>Elagatis bipinnulatus</i>	....	....	....	....	....	.1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Trachinotus carolinus</i>	1.6	4.1	2.9	....	2.9	2.7	8.1	....	....	....	....	....	....	8.4	28.2	31.6	.1	....	....	1.4	3.2	....	.9	6.7	2.1
<i>Caranx bartholomaei</i>	....	.1	....	3.3	....	....	....	....	....	.4	....	....	....	....	.2	....	....	....	....	....	....	....	....	....	....
<i>Caranx hippos</i>	....	....	2.2	.7	.2	.1	1.7	....	....	....	....	....	....	....	....	....	....	....	....	....	.1	.1	8.6	3.4	.5
<i>Chloroscombrus chrysurus</i>	1.0	....	....	....	.4	....	....	....	....	....	....	....	....	....	....	....	<.1	....	....	....	.2	7.3	31.3	3.1	.2
<i>Selene vomer</i>	.1	....	....	....	.2	....	.1	....	....	....	....	....	....	....	....	....	....	....	....	....	.2	.1	....	....	....
<i>Eucinostomus argenteus</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	<.1
<i>Conodon nobilis</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1.9
<i>Bairdiella chrysura</i>	....	....	....	....	....	....	....	....	1.9	1.6	....	11.3	....	....	.4	1.6	.1	3.8	.5	3.2	1.0	117.9	....	....	....
<i>Sciaenops ocellata</i>	....	2.1	....	....	2.2	....	2.4	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Leiostomus xanthurus</i>	16.6	....	2.8	6.6	9.9	7.2	14.1	....	....	....	....	....	....	....	....	4.8	....	....	....	....	....	2.5	....	....	....
<i>Micropogon undulatus</i>	.5	1.7	....	....	....	....	....	....	....	....	....	....	....	....	.8	....	....	....	....	....	....	....	....	....	....
<i>Menticirrhus americanus</i>	2.1	....	....	....	....	....	....	....	....	....	....	....	....	2.7	1.4	....	....	....	....	....	....	....	....	....	....
<i>Menticirrhus atlanticus</i>	....	....	....	....	....	....	....	....	....	....	....	.9	....	....	....	....	....	....	....	....	....	.9	....	.9	....
<i>Menticirrhus littoralis</i>	....	6.2	25.8	24.6	8.6	10.2	25.3	....	....	....	....	....	.4	....	....	3.4	3.4	5.1	.7	7.3	12.3	8.0	1.6	2.6	4.7
<i>Pogonias cromis</i>	....	....	....	....	....	....	3.9	....	....	....	....	....	....	....	....	39.2	12.6	6.1	....	.5	11.6	1.4	1.4	5.0	2.8
<i>Cynoscion nebulosus</i>	1.2	....	1.6	....	4.3	5.7	7.6	2.8	....	....	....	....	....	18.5	....	....	....	....	....	....	....	.3	....	....	.5
<i>Lagodon rhomboides</i>	.6	4.0	....	.6	.6	....	.2	.1	....	.1	.7	.5	....	....	.5	.8	<.1	1.1	2.4	1.6	2.7	9.1	3.1	.3	3.8
<i>Archosargus probatocephalus</i>	....	....	.2	2.4	3.5	9.0	2.4	....	....	....	....	....	....	....	2.3	4.3	2.2	2.4	....	2.3	13.1	....	....	9.0	3.2
<i>Chaetodipterus faber</i>	.3	.2	....	....	.3	.6	.2	....	....	....	....	....	....	....	....	....	....	1.0	<.1	1.0	3.6	1.2	....	....	3.1
<i>Trichiurus lepturus</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.1	....	....	....	....	....
<i>Scomberomorus maculatus</i>	....	.8	....	....	.2	1.1	....	....	....	....	....	....	....	....	....	....	<.1	....	....	....	....	.1	....	.6	....
<i>Peprilus paru</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	4.6	....	....	....	....	....
<i>Paralichthys lethostigma</i>	1.8	....	....	....	.2	1.4	....	....	....	....	....	....	....	....	....	3.8	....	....	.2	.1	.1	.1	....	....	....
Filefish	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	<.1
<i>Lactophrys tricornis</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	.1
<i>Sphaeroides nephelus</i>	....	....	....	....	....	....	....	2.1	....	.3	....	....	....	....	.2	....	....	.3	....	....	....	....	....	....	....
<i>Opsanus beta</i>	....	....	....	....	....	....	....	....	....	....	....	.3	....	....	....	....	....	....	....	....	....	....	....	....	....
<i>Histrio histrio</i>	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	2.3	....	....
Totals	48.0	86.9	102.3	271.8	45.0	84.9	213.6	395.7	5.3	11.0	22.0	48.0	24.7	10,689.6	44.2	135.5	35.6	32.5	46.8	37.9	238.1	172.7	80.6	79.0	43.9

a*—10,651.7 lbs/acre.

TABLE 3

Seasonal occurrence of resident fishes in the surf at Mustang Island, Texas.
Resident fishes are defined as forms which occur on several occasions during a season. Bracketed numbers refer to the abundance rank of a species on the basis of total weight captured during the year.

All year residents	Spring-summer residents	Summer residents	Winter-spring residents
<i>Galeichthys felis</i> (9)	<i>Dasyatis sabina</i> (7)	<i>Rhinoptera bonasus</i> (14)	<i>Bairdiella</i> <i>chrysura</i>
<i>Mugil cephalus</i> (1)	<i>Harengula pensacolae</i>	<i>Elops saurus</i> (16)	
<i>Lagodon rhomboides</i>	<i>Anchoa</i> sp.	<i>Brevoortia patronus</i>	
	<i>Menidia beryllina</i> (13)	<i>Caranx hippos</i> (19)	
	<i>Polydactylus octonemus</i> (2)	<i>Chloroscombrus chrysurus</i> (11)	
	<i>Pomatomus saltatrix</i>	<i>Leiostomus xanthurus</i> (8)	
	<i>Trachinotus carolinus</i> (5)	<i>Micropogon undulatus</i>	
	<i>Caranx bartholomaei</i>	<i>Scomberomorus maculatus</i>	
	<i>Menticirrhus americanus</i>	<i>Peprilus paru</i>	
	<i>Menticirrhus atlanticus</i>		
	<i>Menticirrhus littoralis</i> (3)		
	<i>Pogonias cromis</i> (6)		
	<i>Cynoscion nebulosus</i> (12)		
	<i>Archosargus probatocephalus</i> (10)		
	<i>Chaetodipterus faber</i> (20)		
	<i>Paralichthys lethostigma</i>		

spawning history of this species is fairly well documented for the Texas coast and the seasonal changes encountered in this study agree with spawning and growth habits of pompano (see Gunter, 1958; Springer and Pirson, 1958).

On a basis of weight of fishes per acre, nine of the sixteen species which can be classed as spring-summer residents were amongst the 20 most abundant species for the collecting year.

SUMMER RESIDENTS

Nine species can be classed as summer residents (Table 3). Of the nine, five are amongst the 20 most abundant fishes. *Caranx hippos*, *Chloroscombrus chrysurus*, *Micropogon undulatus*, *Scomberomorus maculatus* and *Peprilus paru* enter the beach populations as summer progresses.

WINTER-SPRING RESIDENTS

One species, *Bairdiella chrysura*, was captured only during the winter and spring periods. Its absence from the beach during summer is unexpected, since it is common in the bays and from deeper water of the gulf shelf.

SPORADICS

Of the total number of 47 species captured, 18 occurred in the catches in a sporadic manner (Table 4). Most of the sporadic occurrences were encountered during the summer months. All of the elasmobranchs and the redfish, *Sciaenops ocellata*, are common just outside the surf zone. Although the redfish was represented only sporadically in the collections, this species is taken commonly in the surf by anglers. Night seining with smaller nets yielded increased numbers of redfish, but why the catch was low during daylight seine hauls is unknown. The results suggest that redfish may move into the shallow surf water primarily at night, or, that redfish are adept at escaping a seine during daylight hours. The latter possibility appears most likely since Gunter has found both redfish and black drum to be wary of boats even when drifting (personal communication).

TABLE 4

Sporadic occurrence of fishes in the surf at Mustang Island, Texas.
Numbers refer to the rank of the individual species on the basis of total weight captured during the year. Sporadic fishes are defined as species that occur on but few occasions during a season.

Spring-summer sporadics	Summer sporadics	Winter and winter- spring sporadics
<i>Syngnathus</i> sp.	<i>Scoliodon terranovae</i> (18) <i>Sphyrna tiburo</i> <i>Narcine braziliensis</i> <i>Dasyatis americana</i> <i>Strongylura marina</i> <i>Centropomus undecimalis</i> (17) <i>Elagatis bipinnulatus</i> <i>Selene vomer</i> <i>Eucinostomus argenteus</i> <i>Conodon nobilis</i> (4) <i>Sciaenops ocellata</i> <i>Trichiurus lepturus</i> Filefish <i>Lactophrys tricornis</i> <i>Histrio histrio</i>	<i>Sphaeroides nephelus</i> <i>Opsanus beta</i>

Relative Abundance of the Various Species of Fishes

In his study of the fishes of the Mustang Island surf, Gunter (1958) indicated the relative "dominance" of several species on the basis of the numbers of each species captured. Similar measures of relative *abundance* can be established from the present data. However, neither numbers of fishes nor relative biomass are a complete index to the *dominance* of a given species in an environment. Of the two measures biomass contains more ecological information. The absolute and the relative abundance of fishes in the surf zone, therefore, are reported preferably in terms of weight of fish per acre.

In ranking the fishes according to yearly abundance, the enormous catch of catfish on March 1, 1961 has been disregarded. Since *Galeichthys felis* from this one collection constituted almost 65% of the entire weight of all fishes captured and, since its presence in large numbers is believed to be the result of breeding movements, its inclusion would bias conclusions on relative abundance. The exclusion of the data for March 1 is in part justified by the fact that large numbers of *G. felis* were captured only for this one sampling, although catfish were resident throughout the year but in lesser abundance. The 20 most abundant fishes are presented on the basis of weight and of numbers per acre in Table 5.

On the basis of weight, *Mugil cephalus* is by far the most abundant fish. The next four most abundant species, *Polydactylus octonemus*, *Menticirrhus littoralis*, *Conodon nobilis* and *Trachinotus carolinus*, when included with *M. cephalus*, constitute 70% of the catch during the year. *Conodon nobilis* cannot be considered as a typical resident of the surf, since it is usually absent from beach seine hauls. If its brief, spectacular appearance is excluded, the other four species still constitute the major proportion of all fishes taken from the surf (63.4%).

When the percentage representation in all catches is expressed on a number of indi-

TABLE 5
Percentage abundance of fishes which occurred in the surf at Mustang Island, Texas*

Species	Standing crop (lbs fish/acre)		Species	Numbers of fish/acre	
	per cent of all catches	cumu- lative percent		per cent of all catches	cumu- lative percent
<i>Mugil cephalus</i>	46.07	46.07	<i>Polydactylus octonemus</i>	44.53	44.53
<i>Polydactylus octonemus</i>	7.54	56.61	<i>Menidia beryllina</i>	11.51	56.04
<i>Menticirrhus littoralis</i>	6.56	60.17	<i>Mugil cephalus</i>	10.16	66.20
<i>Conodon nobilis</i>	5.24	65.41	<i>Menticirrhus littoralis</i>	7.12	73.32
<i>Trachinotus carolinus</i>	4.58	69.99	<i>Chloroscombrus chrysurus</i>	5.21	78.53
<i>Pogonias cromis</i>	3.69	73.68	<i>Trachinotus carolinus</i>	2.65	81.18
<i>Dasyatis sabina</i>	3.38	77.06	<i>Harengula pensacolae</i>	2.59	83.77
<i>Leiostomus xanthurus</i>	2.82	79.88	<i>Conodon nobilis</i>	2.17	85.94
<i>Galeichthys felis</i>	2.52	82.40	<i>Anchoa</i> sp.	1.91	87.85
<i>Archosargus probatocephalus</i>	2.46	84.86	<i>Galeichthys felis</i>	1.80	89.65
<i>Chloroscombrus chrysurus</i>	1.91	86.77	<i>Lagodon rhomboides</i>	1.63	91.28
<i>Cynoscion nebulosus</i>	1.90	88.67	<i>Leiostomus xanthurus</i>	1.33	92.61
<i>Menidia beryllina</i>	1.75	90.42	<i>Dasyatis sabina</i>	1.25	93.86
<i>Rhinoptera bonasus</i>	1.72	92.14	<i>Menticirrhus atlanticus</i>	0.99	94.85
<i>Lagodon rhomboides</i>	1.44	93.58	<i>Caranx hippos</i>	0.87	95.72
<i>Bairdiella chrysura</i>	1.07	94.65	<i>Bairdiella chrysura</i>	0.61	96.33
<i>Elops saurus</i>	0.91	95.56	<i>Pogonias cromis</i>	0.39	96.72
<i>Centropomus undecimalis</i>	0.86	96.42	<i>Chaetodipterus faber</i>	0.29	97.01
<i>Scoliodon terranova</i>	0.84	97.26	<i>Caranx bartholomaei</i>	0.27	97.28
<i>Caranx hippos</i>	0.77	98.03	<i>Archosargus probatocephalus</i>	0.19	97.47

* Data are for the 20 most abundant fishes of the 47 species taken, according to the respective system of measurement.

vidual basis (Table 5) the order of abundance of species is slightly changed. However, the three highest ranking species on the basis of weight are still included among the four most numerous species.

When both numbers and biomass are considered jointly, tendencies are revealed which correlate with information that has been accumulated on the productivity of the beach environment. First, *Mugil cephalus* and *Polydactylus octonemus* are predominantly plankton feeders (*M. cephalus* is more often considered a grazer, cf. Darnell, 1958). On a weight basis, *M. cephalus* and *P. octonemus* constitute 53.61% of the total yearly catch. If only the catches for June, July and August are considered they still constitute 47.76% of the total biomass. Thus the most abundant surf fishes are plankton feeders. Furthermore, their maximum abundance during spring and summer parallels the maximum abundance of plankton in the surf (McFarland, 1963).

Of the remaining 18 species listed in Table 5, that are ranked on the basis of weight, only *Harengula pensacolae*, *Anchoa* sp. and possibly *Menidia beryllina* can be classed as plankton feeders. When both numbers and weight are considered, *Menticirrhus littoralis* is less abundant than either *M. cephalus* or *P. octonemus*, but distinctly more abundant than all other species (Table 5). *Menticirrhus littoralis* feeds primarily on bottom invertebrates (Darnell, 1958). The remaining species are bottom feeders also, living off various crustaceans and molluscs or, in a few instances, other fishes. However, many of the fishes have been observed to consume large quantities of zooplankton when it is abundant in the surf. Direct examination of the stomach contents of *Mugil cephalus*, *Trachinotus carolinus*, *Caranx hippos* and *Chloroscombrus chrysurus* revealed that their stomachs were often full of crustacean larvae. How generalized plankton feeding might be to surf fishes that normally feed on bottom dwelling forms is not known; also, it is not known whether phytoplankton cropping occurs during periods when zooplankton are not abundant in the surf, such as during mid-summer.

A comprehensive analysis of the food habits of the fishes in the surf at the various seasons would be valuable in establishing whether the smaller biomass of bottom feeding fishes relative to plankton feeding fishes is related to an inability of the former to utilize plankton, to a lesser availability of the bottom fauna or, to both.

Comparison With Previous Work

In his 1958 paper, Gunter was able to demonstrate for the year 1947-48 that a seasonal succession occurred in the fish populations on the Gulf beach. Two species, *Trachinotus carolinus* and *Harengula pensacolae* were the most numerous and constituted 68% of the catch. *Mugil curema*, which was the third most abundant species constituted about 6% of the catch. Thus three species comprised nearly 75% of the total number of fishes taken throughout the year. The results reported by Gunter are for the most part representative of fishes smaller than 100 mm in total length. In this study net selectivity eliminated fishes smaller than 40 mm standard length. Thus, present data overlap Gunter's findings and extend them to include the larger fishes. The most conspicuous difference between the studies are the decreased representation of *H. pensacolae* and the virtual replacement of *M. curema* by *M. cephalus* in present collections. For example on July 19, 1960, only one specimen of *H. pensacolae* is reported in the catch (Table 1), but 734 individuals were taken by the small fine mesh net used to surround the bag prior to beaching the large net. Most certainly, *H. pensacolae* would constitute a

considerable portion of the standing crop if specimens of less than 40 mm standard length could be included. The replacement of *M. curema* by *M. cephalus* is baffling, but ecologically there is probably little difference between the two forms.

Gunter (1958) suggests that during any given season the species composition might fluctuate from year to year and gives examples for the years of 1945 and 1947-48. The heavy representation of *Trachinotus carolinus*, *Harengula pensacolae* and *Polydactylus octonemus* that he reports are certainly characteristic of the more abundant species for this study (Table 5), even though *H. pensacolae* probably constituted a greater bulk of the total population than indicated. Thus, in spite of changes in species composition from year to year, the more abundant species and particularly similar ecologic types are of constant occurrence. It is considered of major importance to the survival of the surf fish stocks that the most abundant species are plankton feeders, or are potentially capable of feeding on plankton.

Primary Productivity of Plankton and its Relation to the Biomass of Fishes

Results on plankton productivity of the Mustang Island surf zone indicate that net photosynthesis is lowest in winter, sporadic in spring and increases to its highest values in the summer-fall period (McFarland, 1963). Plankton respiration is lowest in winter, but peaks during spring and then levels off at a summer rate four times the winter rate. The increased plankton abundance of the spring-summer-fall period, coincides with the increase in the biomass of fishes.

A major question that can be posed, therefore, is whether the abundance of plankton in the surf is sufficient to serve as the primary food source for the fish populations. A final answer is at present not available. However, rough estimates of fish metabolism and carbon requirements suggest that the abundance of plankton is sufficient to supply the energy needs of the fish populations.

If the average summer oxygen consumption of the beach fishes is assumed to be 0.5 ml/gram wet weight per hour, then the total consumption of oxygen by beach fishes would be 777 grams/surface acre per day (based on the mean biomass of 100 lbs. fish per acre). If the R.Q. of all surf fishes averaged 0.80, then 860 grams of carbon dioxide or 232 grams of carbon (860×0.27) would be produced metabolically per acre per day. Growth of fishes per day, as based on Hellier's (1962) data for fishes in the Laguna Madre, Texas, would not exceed 10 grams of carbon/acre of surf per day if the carbon assimilation were 100% efficient. Correcting for a food conversion by the fishes of only 10% (Brown, 1957) yields a total daily organic carbon requirement of from 300 to 350 grams/acre. The only known primary producing source capable of supplying this daily carbon requirement which occurs in the beach environment is the surf plankton.

The mean summer net photosynthesis of plankton in the surf at Mustang Island was 1 gram O_2/m^3 per day. Converting the oxygen production to assimilated carbon by use of a factor of 1.25 (Ryther, 1956) yields a production of 5,688 grams organic C/acre per day. The carbon assimilation, therefore, is from 15 to 18 times in excess of the daily carbon requirement of the fishes. The carbon requirement of the infauna was not measured, but it seems unlikely that it would exceed the requirement of the fishes. Indeed,

judging from the data of Loesch (1957) on the biomass of *Donax* in the Mustang Island beach the total infauna probably represents less than 5 and certainly less than 10% of the fish biomass.

Thus, even if the beach was a closed system, the summer plankton production would be more than sufficient to supply the food requirements of the fish populations. However, the beach environment is an open system and the water mass and its contained plankton are constantly imported to the beach during summer from the open Gulf of Mexico. Neither organic importation nor the biomass of plankton in the water have been measured, but judging from the high plankton respiration and the strong longshore current systems that traverse the beach (McFarland, 1963) it seems probable that the daily import and export of plankton to and from the beach are several orders of magnitude in excess of the energy requirements of the beach fauna. For instance, a longshore current of one knot would exchange the water mass over a given area of beach nearly 700 times per day. Yet longshore currents normally exceed one knot and, therefore, water exchange often would exceed a daily turnover of 700. Under these conditions, if the plankton biomass was moderate and the biomass of surf fishes during summer was relatively stable as the data indicate, then the importation of plankton to the beach in currents would be sufficient to meet the energy requirements of the beach populations.

The intricacies of the energy exchange between the beach populations remains to be balanced. However, the trophic dependence of the beach fauna of the Texas coast on plankton, at least during summer, seems certain. This conclusion is supported by the evidence for a large net productivity of plankton, the probable high importation and exportation of plankton to and from the beach and, the demonstration that the most abundant fishes in the surf are either plankton feeders or are capable of plankton feeding. In further support of this contention is the fact that the most abundant mollusc of the infauna, *Donax variabilis*, is also a plankton feeding organism.

Summary

(1) The seasonal abundance of fishes with respect to numbers and biomass for the surf zone at Mustang Island, Texas, are reported for the year 1960-61. Results reveal that both species composition and total abundance are lowest in winter and increase during the spring-summer periods.

(2) During winter an average of four species of fishes were taken by seining, whereas the summer average was 16 species. A total of 47 species were captured during the collecting year and are classified as all year, spring-summer, summer, and winter-spring residents, or, as sporadic occurrences.

(3) The average standing crop of fishes during winter was 25.8 pounds of fish per surface acre of surf (ca. 4,550 m³ water) and increased to an average of 103.2 pounds during the summer.

(4) The striped mullet, *Mugil cephalus* constituted 46% of the total catch on a weight basis and was by far the most abundant species. The next five most abundant fishes were *Polydactylus octonemus*, *Menticirrhus littoralis*, *Conodon nobilis*, *Trachinotus carolinus* and *Pogonias cromis*. Together they constituted 27.61% of the total catch.

(5) The relative abundance of the fishes are compared with previous studies; it is concluded that a similar species composition is maintained from year to year, although a

particular species may vary in rank or be replaced by a close relative or ecologic counterpart.

(6) The theoretical carbon requirement of fishes is calculated and related to the availability of carbon in the plankton. It is concluded that the recruitment of plankton from net productivity and from importation is at least several orders of magnitude in excess of the food requirements of the fishes.

Acknowledgments

Innumerable individuals assisted in the seining procedures during the course of this study. Their constant willingness to help is gratefully acknowledged and it is hoped that the participants will forgive the necessary omission of their names. One individual, Mr. Emilio Guerra, maintained the equipment, measured and counted fish and performed often near impossible tasks throughout the period of the study. Much of the data must be accredited to his perseverance. The work was financed by an interagency contract between the Texas Game and Fish Commission and the Institute of Marine Science, University of Texas, Port Aransas, for studies of fish stocks and productivities.

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Growth and Decay of *Penicillus capitatus* Lamarck in the Lower Laguna Madre of Texas¹

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Abstract

The entire standing population of *Penicillus capitatus* Lamarck in the lower portion of the Laguna Madre was destroyed by reduced salinity in the fall of 1958. The area had almost completely recovered from the effects of low salinity by 1960.

Studies of the growth and calcium content of *Penicillus capitatus* in the extreme lower portion of the Laguna Madre were made for May 1961 through February 1962. Characteristics of growth and destruction of this tropical form in its northern range were recorded as well as observations on regeneration of the exposed portions of *Penicillus*. Mean dry weight of *Penicillus* during this time was 5.14 grams per core of 4 inch diameter. Mean calcium carbonate weight was 1.99 grams per core of 4 inch diameter.

In January 1962, low temperatures destroyed almost the entire *Penicillus* population in the lower Laguna Madre of Texas. In January, 1963, a remnant portion of the former population remains, scattered among an area dominated by the sea grass, *Thalassia*.

Introduction

The occurrence of *Penicillus capitatus* in the extreme southern portion of the lower Laguna Madre is of considerable interest because it is the principal calcium depositing alga which occurs in this area. Humm and Hildebrand (1962) reported its occurrence on muddy, sandy flats in three to five feet of water between the causeway bridge and the ship channel at Port Isabel. In some areas, there were several hundred plants per square meter. The muddy, sandy bottom of much of the shallow portion of the lower Laguna Madre has from time to time been heavily populated with *Penicillus*. In some areas, *Penicillus* has been the single conspicuous dominant, and in others it has shown scattered occurrence among the rhizomes of the sea grass, *Thalassia testudinum* König and Sims.

Little is known about the growth or reproduction of this calcareous depositing algae which occurs in tropical and sub-tropical waters. Woronin, as early as 1861, reported the presence of spherical bodies on *Penicillus* which he thought might be zoosporangia. A. and E. S. Gepp, in their monographic account of *Penicillus* in 1911, discussed the earlier reports of reproduction of the genus and stated that no satisfactory information had been published. Fritsch (1956) maintains that so-called reproductive organs reported for *Penicillus* have proved to be epiphytic organisms.

Elsie Kupper (1907) studied regeneration in *Penicillus* by cutting off the "heads" of a number of these algae and found that after 38 days, a new tuft of loose filaments had

¹ Based on observations and measurements from 1958 through 1962 with the aid of NSF Grant 17867.

begun to form. A. and E. S. Gepp (1911), in reviewing Miss Kupper's work, stated that the figure in her text also showed that similar filaments had broken out singly or in groups along the stipe.

The purpose of this paper is to present data on the vegetative growth of *Penicillus capitatus* and to discuss the environmental factors which cause drastic fluctuations in its populations in this area and prevent its extension farther north along the Texas Coast.

Methods

Visual observations of the *Penicillus* population in the area studied were begun during the spring of 1958. At that time the species contributed significantly to the biomass of the area, but after its destruction in the fall of 1958, it did not reappear in any sizeable quantity until the summer of 1960. During 1961, a study was begun in an effort to determine the growth rate of *Penicillus* and the rate of calcium carbonate deposition. An area was chosen for investigation in which the *Penicillus* growth was luxuriant and other macroscopic forms limited or lacking. Samples of the vegetation were taken each week.

Dry weight bases were used to determine the ratio of the total weight and the calcium carbonate content of the *Penicillus* population. The sampling was done by taking cores of material from *Penicillus* beds in a relatively shallow bay area which borders the extreme southern tip of Padre Island. Cedar posts were used to mark the location of the beds and the samples were taken by stepping off a random number of spaces from a post in a random direction and then securing a core. Six cylindrical cores four inches in diameter taken from these areas, each covering approximately two acres in which *Penicillus* was the most abundant form, constituted the sample each time.

Each core was washed in a 1/16 inch mesh screen box to separate the *Penicillus* plants from the bottom sediments. The *Penicillus* plants, consisting of rhizoids, stipe and head, were rewashed, dried at 105° C for 24 hours and weighed. The dried specimens were then treated with a 10% solution of HCl to remove the calcium carbonate, which is deposited in the form of aragonite. The decalcified specimens were then dried at 105° C for 24 hours and reweighed. The difference in dry weight of the specimens before and after treatment with HCl gives an indication as to the amount of CaCO₃ present.

Salinity and temperature determinations were made at the level of the stipes each time the samples were collected. Salinity measurements were made with the aid of a precision calibrated specific gravity hydrometer and checked by the electrical conductivity method. Salinity values were expressed in parts per thousand. Water temperatures were recorded with the aid of a 0° to 100° Centigrade thermometer graduated to read in tenths of a degree.

Field observations for the most part were made by wading or by use of a face mask which permitted observations of the attached forms when visibility permitted. During 1961, some studies were made by use of a boat and a glass bottomed tub for rapid scanning of an area, followed by the use of the mask for more detailed observations.

Penicillus plants were uprooted from the mud bottom and transplanted to the laboratory. They were placed horizontally in marine water of 30 ‰ and kept at room temperature in subdued light. Plants were also moved into aquaria and replanted into mud taken from the area in which they were collected, but results obtained from such transplants have not been suitable because of the lack of uniformity in response to transplantation.

Results and Discussion

During the summer of 1958, the lower Laguna Madre in the vicinity of the Port Isabel-Padre Island causeway exhibited an extensive and luxuriant growth of *Penicillus capitatus*. The growth occurred in water one to six feet in depth and provided a dense stand of several hundred plants per square meter on much of the mud and sand bottom of the entire area. In areas dominated by spermatophytes, *Penicillus* occurred as single plants or in small groups of two or three interspersed among the grasses. The plants have not been observed north of Port Mansfield in the Laguna Madre of Texas.

In the fall of 1958, the Rio Grande Valley watershed area south of Falcon Dam experienced a series of unusually heavy rains resulting in much local flooding. The floodway system was opened to carry the excessive flood water into the Laguna Madre at a point where the Arroyo Colorado joins the bay. At this time salinity of the lower bay was stationary at 8 ‰ for several weeks. The entire population of *Penicillus* disappeared at this time. The only evidence of their past existence was the dead stipes that contained calcium carbonate.

During 1959, one small area consisting of patches of *Penicillus* was discovered between the ship channel and a deep trench that had been dug when the causeway was built. The salinity around this area may not have changed as drastically as that in the much shallower bay. The immediate area surrounding the remnant bed was the first to be re-populated by *Penicillus* and each successive visual inspection revealed plants further from the place where they were first found. The species continued to re-establish itself over the area it had formerly occupied. In the fall of 1960, it was nearly as abundant in the extreme lower bay area as before the influx of fresh water.

During the summer of 1961, water temperatures were normal. Generally in the early morning, water transparency was good, but by mid-morning, the wind disturbed the water and the resultant turbidity was such that only 10 to 15% of the surface light reached the floor of the bay which supported *Penicillus* growth at a depth of approximately two feet. Rainfall was nearly normal.

During the summer of 1961, *Penicillus* was found occupying a prominent position in the extreme lower portion of the Laguna Madre reaching northward about five miles from the causeway. It occurred as the conspicuous dominant attached alga located chiefly as small to larger areas among the grassy areas of the bottom. It was the only attached inhabitant in the areas recently disturbed by dredging operations. In areas where the sea grasses were well established, *Penicillus*, although present, consisted of small scattered groups of isolated plants.

Data for the growth of *Penicillus* and the rate of calcium carbonate deposition are graphically represented in Fig. 1. Salinities and temperatures are also shown.

During the months of August and September, there was a continuous visible change in the *Penicillus* population with the disappearance of the older grayish-green stipes and the appearance of the young brilliant green stipes. Death of older plants near the center of the bed occurred, and there was an extension of the bed into adjacent areas by the new stipes. The calcium carbonate content of the new stipes was low, but as carbonate deposition progressed there was a color change of the stipes to grayish-green.

On September 10, 1961, tropical hurricane "Carla" swept into the middle of the Texas coast. In several areas, Padre Island was cut by the Gulf waters and high waves and wind pushed much water into the bay. The water level in the lower bay remained at

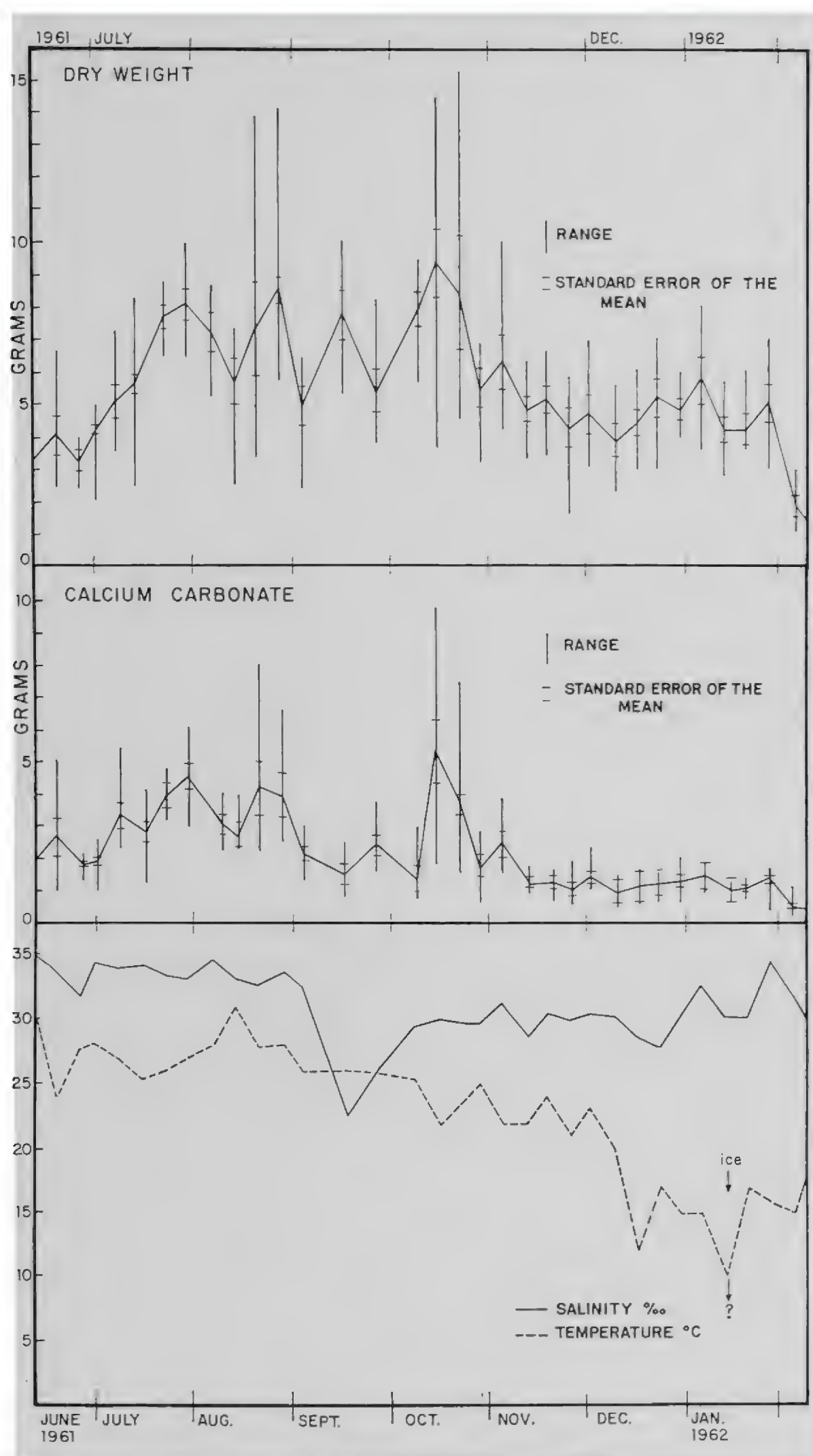


FIG. 1. Fluctuations in temperature, salinity, and dry weight and calcium carbonate content of populations of *Penicillus* in the lower Laguna Madre of Texas, June 1961 through January 1962. Weights are in grams per four inch diameter circle.

a higher than normal level for nearly a month after the storm had struck. Heavy rains followed the hurricane with an accompanying decrease in salinity to 22.5 ‰. This change in salinity had little visible effect on the *Penicillus* population.

On January 9, 1962, a severe cold front moved across the bay area. A thin sheet of ice formed on January 10 and 11, 1962, but with wind from the north, the ice was piled approximately 16 inches deep on the *Penicillus* area that had been used for study purposes. Sediment was also laid down on top of the plants so that only the heads protruded in much of the area. Within one month, the entire *Penicillus* population throughout the entire lower Laguna Madre died, leaving only fragments of the calcified stipes littering the area. Examination of known areas where *Penicillus* had occurred before failed to disclose a single live specimen.

On January 9, 1962, before the cold front moved in, the weather was balmy, the tide low, visibility excellent. Several *Penicillus* stipes with heads intact and a portion of the rhizoidal mass attached to the basal ends was moved into the laboratory and kept in a horizontal position in an aquarium containing water with salinity of 30 ‰. Within three weeks new growth appeared in the form of multiple stipes from the basal region where the rhizoidal mass was attached to the stipe. Filaments comprising the original head continued to elongate. Along the stipe, individual filaments emerged and formed single vertical filaments. Fig. 2 shows these plants after the formation of vegetative structures and before they were transplanted to an aquarium which contained a layer of material which had been taken from the bottom of the bay. The stipes continued to produce almost normal appearing plants, with a rhizoid mass generating from the base of each stipe. The heads were more loosely formed than were those of the original plants. The single filaments which had arisen from the side of the stalk persisted for over a month but did not change in appearance. Under microscopic examination, they were found to be identical to those filaments taken from the heads.

The mass of rhizoids in the *Penicillus* bed at the time of the freeze did not appear to



FIG. 2. *Penicillus* plants as taken from the bay and placed horizontally in an aquarium. One or more stipes formed at the basal end of the plant and loose filaments arose from the sides of the plant and at the apex.

have been destroyed. Some of this material was transplanted to aquaria in the laboratory where single *Penicillus* filaments emerged. In about two weeks they grew to a length of two inches, persisted for several weeks, and then disappeared. No comparable appearance was observed in the bay, but they might easily have been over-looked because of their diminutive size and the typical poor visibility following the destruction of the major portion of the plant and animal life in the lower bay area. They did not produce identifiable stipes in the bay and the rhizoids became much attenuated and gradually less abundant until they were no longer detectable in the mud bottom.

In July, 1962, small patches of young *Penicillus* stipes were discovered in the same vicinity as those which appeared in 1959 following destruction of the population by the reduced saline conditions. They were confined to areas less than one meter in diameter, scattered among a thickly populated area of *Thalassia*. The plants confined to these open areas were not numerous and none was found scattered among the *Thalassia*.

The plants have continued to extend their area at the margin of each small patch of existing *Penicillus* until the fall of 1962. At this time plants could be found intermingled with the *Thalassia*, covering an area of approximately twenty acres.

Acknowledgment

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Notes on the Fringed Pipefish, *Micrognathus crinigerus*, From the West Coast of Florida

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Abstract

Occurrences of eggs, embryos, and sizes are reported for collections of the fringed pipefish, *Micrognathus crinigerus*, made at Cedar Key and Old Tampa Bay, Florida from 1950 to 1957. *M. crinigerus* had the shortest breeding season of any syngnathid commonly found on the grass flats, breeding from April 2 to September 16. Lengths and numbers of eggs and embryos were similar for males and females. The sex ratio varied with season.

Introduction

The fringed pipefish, *Micrognathus crinigerus* (Bean and Dresel), is a small, little known fish, which ranges from Miami, Florida to Cameron, Louisiana and is found at Royal Island, Bahamas (Herald, 1942). There are doubtful data on one specimen from Albrook Island, Brazil (Herald, 1942). It lives and breeds in the shallow grass flats. Collections made from the West Coast of Florida are reported as evidence for some conclusions about the life history of the species.

Methods

The fish were caught in push nets, beam trawls, and dip nets while collecting *Hippocampus zosterae* Jordan and Gilbert during the years 1950 to 1957. Specimens were measured, sexed, and their eggs or embryos examined. Individuals with brood pouches were considered males. No pouched males under 60 mm were taken (Fig. 1). Females as small as 45 mm were recognized by microscopic inspection of intact ovaries. The smallest fish were not sexed. Most unsexed fish between 53 and 60 mm (Fig. 1) probably were males too young to have brood pouches.

Prior to counting, embryos of *M. crinigerus* were removed from the males by spreading the right and left flaps of the brood pouch and teasing out the embryos. Eggs were counted in the intact ovaries. Ovaries were removed from the body cavity of the female by making an incision along the right side from the vent to the region of the pectoral fin. They were lifted out with the head of a pin and severed from the fish at the urogenital opening.

The ventral body wall, the dorsal surface of the brood pouch, and the adjacent flap of the brood pouch are dented by cup-shaped depressions which hold individual embryos in place. The embryos are arranged in the brood pouch of the male in one, two, three, or, if

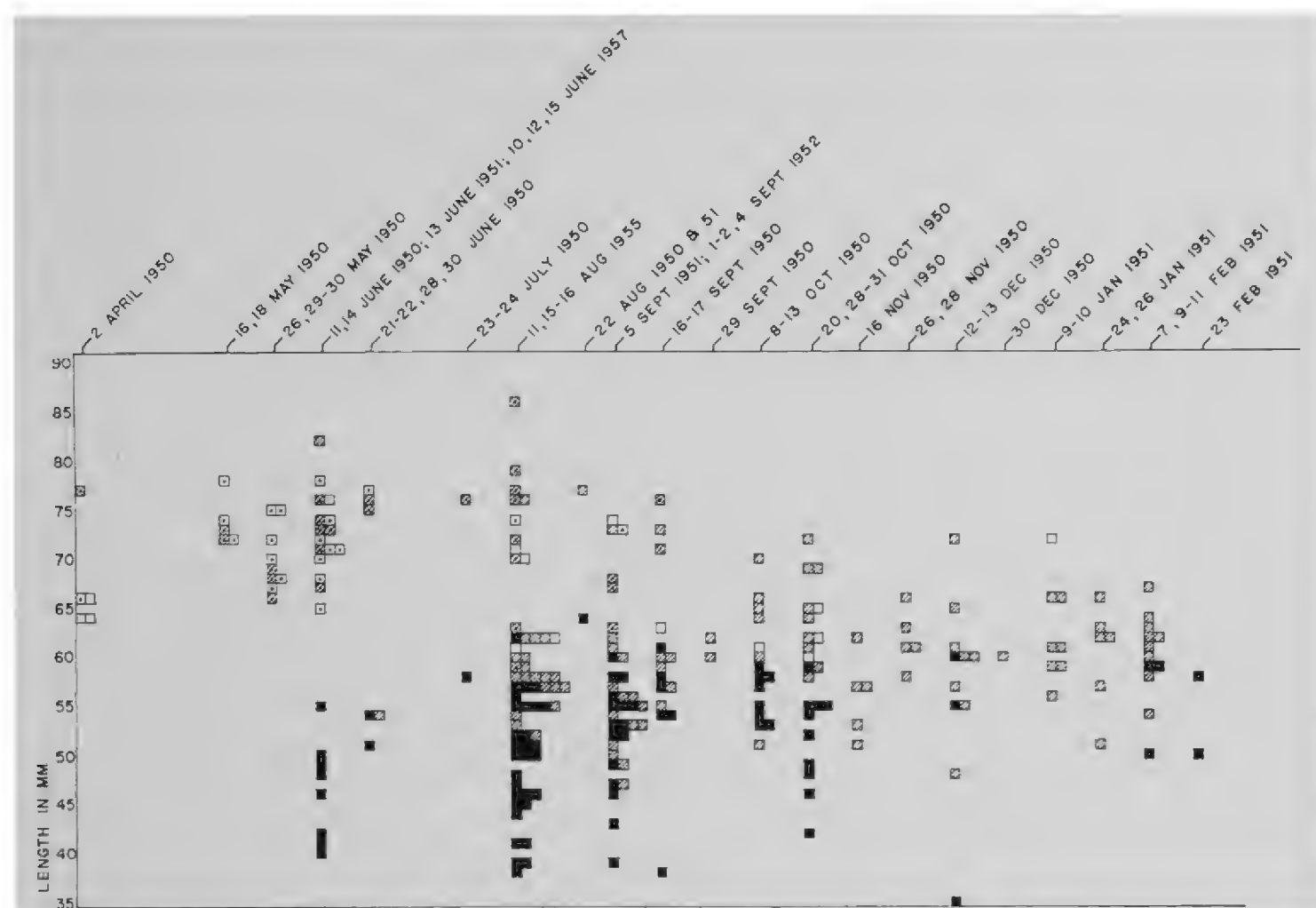


FIG. 1. Seasonal lengths of *Micrognathus crinigerus* at Cedar Key, Florida. Unsexed fish are represented by black squares, females by crosshatched squares, and males by clear squares. A dot in the square either indicates yolked eggs in females or embryos in males.

the embryos are numerous, in four rows. One and two rows are arranged horizontally. More rows frequently result in a staggered vertical arrangement of embryos. The posterior ends of the right and left ovaries are fused into a common chamber. The anterior two-thirds to three-fourths of the maturing ovaries are separate, are equally developed, and contain yolked eggs arranged vertically in one to three rows. A horizontal row may be added when eggs are numerous. Unyolked eggs are on the ventral surface of the ovary.

Results

The distributions of specimens by size and according to sex breeding condition are given in the chronological graph in Fig. 1. The number of eggs is related to the cube of the length in Fig. 2 (Nicholls, 1958).

Most large specimens of *M. crinigerus* were collected in the summer. The scarcity of these fish during the winter may indicate that *M. crinigerus* like *H. zosteræ* (Strawn, 1958) survives only one winter and that the largest individuals are between seven and seventeen months of age. On the West Coast of Florida *M. crinigerus* is common in *Sargassum* floating in channels. It is similar to the pigmy seahorse, *H. zosteræ*, in its intimate association with plants. It twists its body around plants and assumes a range of colors matching the colors of plants among which it lives.

Sex ratio varied with season. Between the vernal and autumnal equinoxes 26 males and 30 females of *M. crinigerus* over 65 mm in length were taken. Between the autumnal and vernal equinoxes 2 males and 14 females 65 mm or longer were collected. These sex

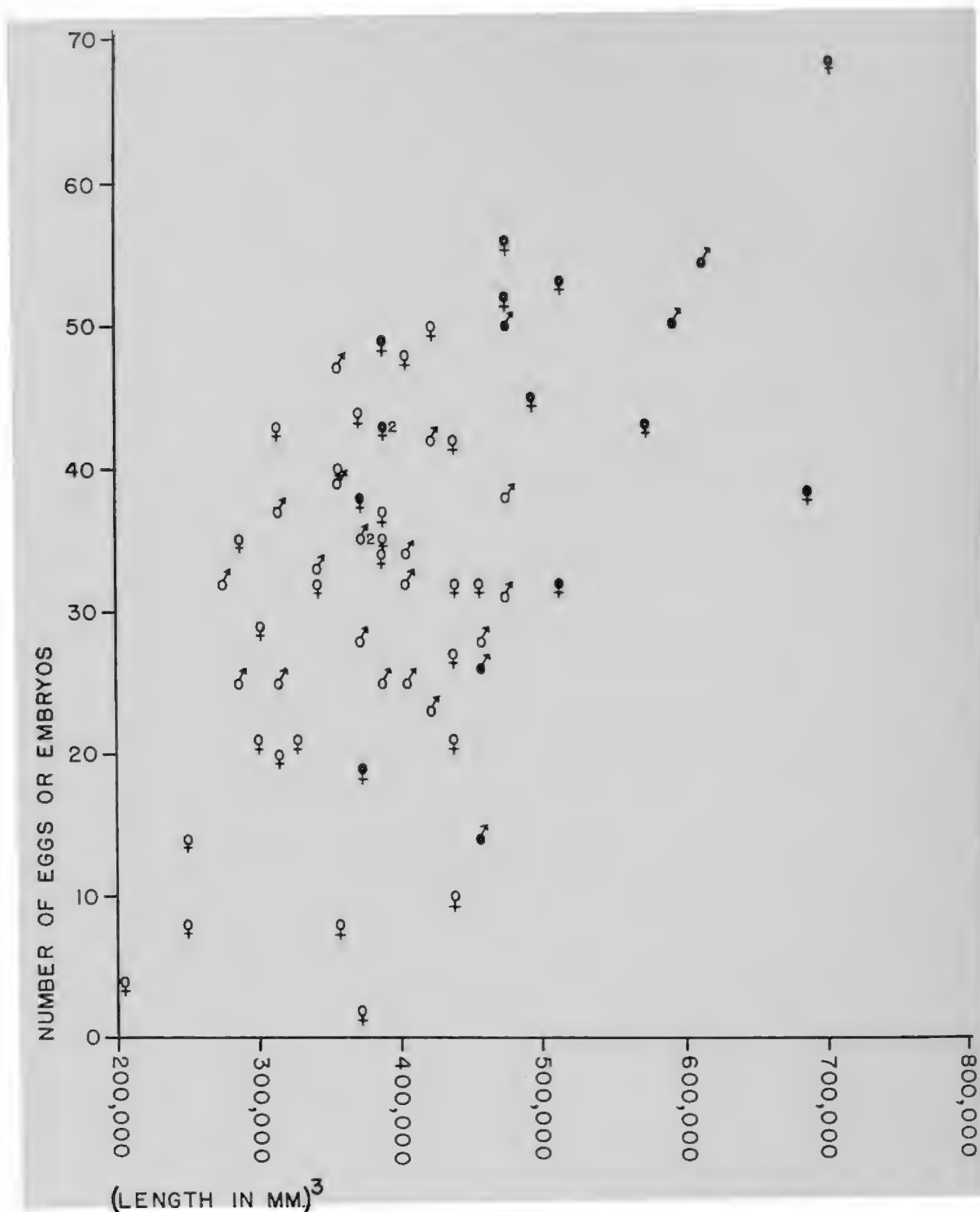


FIG. 2. Egg and embryo counts made on *Micrognathus crinigerus* from Cedar Key and Old Tampa Bay. The length in mm was cubed because egg number increases as the cube of the length for most fishes (Nicholls, 1958). Only males with undamaged pouches and females with medium to large sized eggs are used in this figure. Solid symbols represent Old Tampa Bay fish; open ones represent Cedar Key fish. When the symbol represents more than one fish, the number is given to the right of the symbol.

distributions gave a χ^2 value of 4.7 and differ at the 0.05 significance level. Strawn (1958) found a reverse seasonal sex distribution in *H. zosteræ*. Males of *H. zosteræ* were about as abundant as females in winter collections and were greatly outnumbered by females in most summer samples.

The lengths of the two sexes appeared similar (Fig. 1). The largest individual was a

female in seven out of thirteen collecting periods that yielded both sexes. The sympatric syngnathid, *H. zosteræ*, also had males and females of similar size, but *Syngnathus scovelli* (Evermann and Kendall) had females that average much larger than the males.

M. crinigerus had the shortest breeding season of any syngnathid commonly found on the grass flats. Pregnant males were taken at Cedar Key from April second through September first and females with yolked eggs from April second through September sixteenth (Fig. 1). Reid (1954) collected breeding males in May, August, and September. The breeding season of *M. crinigerus* appeared shorter than that of *H. zosteræ* in the Tampa Bay area. A collection of *H. zosteræ* made south of the west end of Gandy Bridge, Old Tampa Bay, Pinellas County, Florida on February 17 and 18, 1951 contained many females with ripe eggs and numerous pregnant males. However, none of six large female *M. crinigerus* taken in the collection had yolked eggs and none of five large males was pregnant. Females with large eggs and pregnant males of *M. crinigerus* were taken at this locality on March 27, 1951. *H. zosteræ*, at Cedar Key, starts breeding in February and stops in October (Strawn, 1958). *S. scovelli* breeds all year at Cedar Key (Reid, 1954). Reid (1954) collected either females with yolked eggs or pregnant males of *Syngnathus floridae* (Jordan and Gilbert) during all months. The breeding season of *H. zosteræ* appears correlated with number of hours of sunlight per day rather than with temperature (Strawn, 1958). Data in Fig. 1 suggest a similar correlation for *M. crinigerus*.

The smallest male containing embryos was 65 mm. During the breeding season 20 out of 26 Cedar Key males 65 mm or over contained embryos. Twenty-six of thirty Cedar Key females, 65 mm or larger, taken during the breeding season, contained yolked eggs. Only three females below 65 mm (two 63 mm and one 59 mm) had yolked eggs.

The number of large yolked eggs in a female was similar to the number of embryos in a male. Tampa Bay fish were larger and contained more eggs and embryos (Fig. 2). The number of embryos in the pouches of Cedar Key males varied from 23 to 47 and the number of large eggs in females varied from 2 to 50. Embryo number varied from 14 to 54 in Tampa Bay males and the number of medium to large eggs varied from 19 to 68 in Tampa Bay females. The two large eggs in the 72 mm Cedar Key female (Fig. 2) probably were not discharged during breeding and did not represent a full batch of eggs. Fecundity varied with the season in samples of *S. scovelli* (Joseph, 1957) and in *H. zosteræ*. Seasonal variations in the fecundity of *M. crinigerus* undoubtedly occurred and add to the variation in embryo and egg numbers seen in Fig. 2. However, samples were too small to observe differences among them.

Collections made at Cedar Key in September of 1958 yielded no specimens of *M. crinigerus*. Springer and Woodburn (1960) found none in the Tampa Bay area following the severe winter of 1957–1958. This coldest winter in 50 years (Springer and Woodburn, 1960) may have destroyed the populations in these areas.

Other Species

Other syngnathids commonly found on the grass flats, the dusky pipefish, *S. floridae*, and the gulf pipefish, *S. scovelli*, are less specialized for clinging to plants and for matching the various colors of the surrounding plants. Two more syngnathids, the spotted seahorse, *H. erectus* Perry, and the chain pipefish, *S. louisianae* Günther were

sometimes found on the grass flats but appeared to be strays from deeper water. In extensive collecting of intertidal areas on the coast of North Carolina, Florida, and Texas the second author has taken no pouched males of *S. louisianae*. Springer and Woodburn (1960) in their study of the fishes of the Tampa Bay area took only one recognizable male of *S. louisianae* (a non-pregnant individual).

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Cell-Diameter Frequency Distributions of the Planktonic Diatom *Rhizosolenia alata*

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Abstract

The dispersal pattern for *Rhizosolenia alata* in inshore waters of Mississippi is presented. Cell-diameter frequency distributions of samples taken at various times in Biloxi Bay and Mississippi Sound during a post-bloom situation in the summer were compared by the chi-square test. The wider *Rhizosolenia alata* remained in the surface layer and were transported toward the sea while the narrower cells settled to be transported landward. *Rhizosolenia alata* was the most numerous species of the genus and was found to increase in abundance as the salinity increased. *Rhizosolenia setigera* and *Rhizosolenia stolterfothii* showed maximum concentrations in the intermediate salinities of the Bay.

Introduction

An attempt has been made to follow the dispersal of *Rhizosolenia alata* by comparing the cell-diameter frequency distributions of samples taken at various locations in the inshore waters of the Mississippi coast. Knowledge of the drift-distribution of populations in estuarine situations, in addition to its intrinsic value, permits an evaluation of the influence of these drifts on studies of seasonal distribution. Bandel (1940) has considered the colonization of the Darss Sill region of the Baltic by *Rhizosolenia* from the more saline Kattegat and North Sea. Hulburt (1956) commented on diatoms entering Great Pond from Vineyard Sound, and Simmons and Thomas (1962), recognized a river association and a Gulf association of diatom species and discussed the mixing of these associations off the Mississippi Delta. However, in none of these works were the derived populations actually matched with populations from the assumed place of origin. If the cell-diameter frequency distributions of the populations in question are compared, one can evaluate statistically the likelihood of one population being derived from another and can further deduce how the population may have been altered during horizontal transport.

In addition to dispersal the question of salinity tolerance is quantitatively considered. Gran (1905), Hustedt (1930), Cupp (1943), Freese (1952), Curl (1959), and others have categorized various species as "brackish," "neritic" or "oceanic," but have not attempted to determine any more exact relationship on the basis of field data, although Curl and McLeod (1961) have determined in the laboratory the effect of salinity on the rate of photosynthesis in *Skeletonema*.

Davis Bayou, Biloxi Bay and Mississippi Sound were investigated (Fig. 1). They are shallow, turbid, stained and of low transparency. The bottom is a soft mud. General descriptions of the area of investigation may be found in the work of Priddy et al. (1955) and Moore (1961).

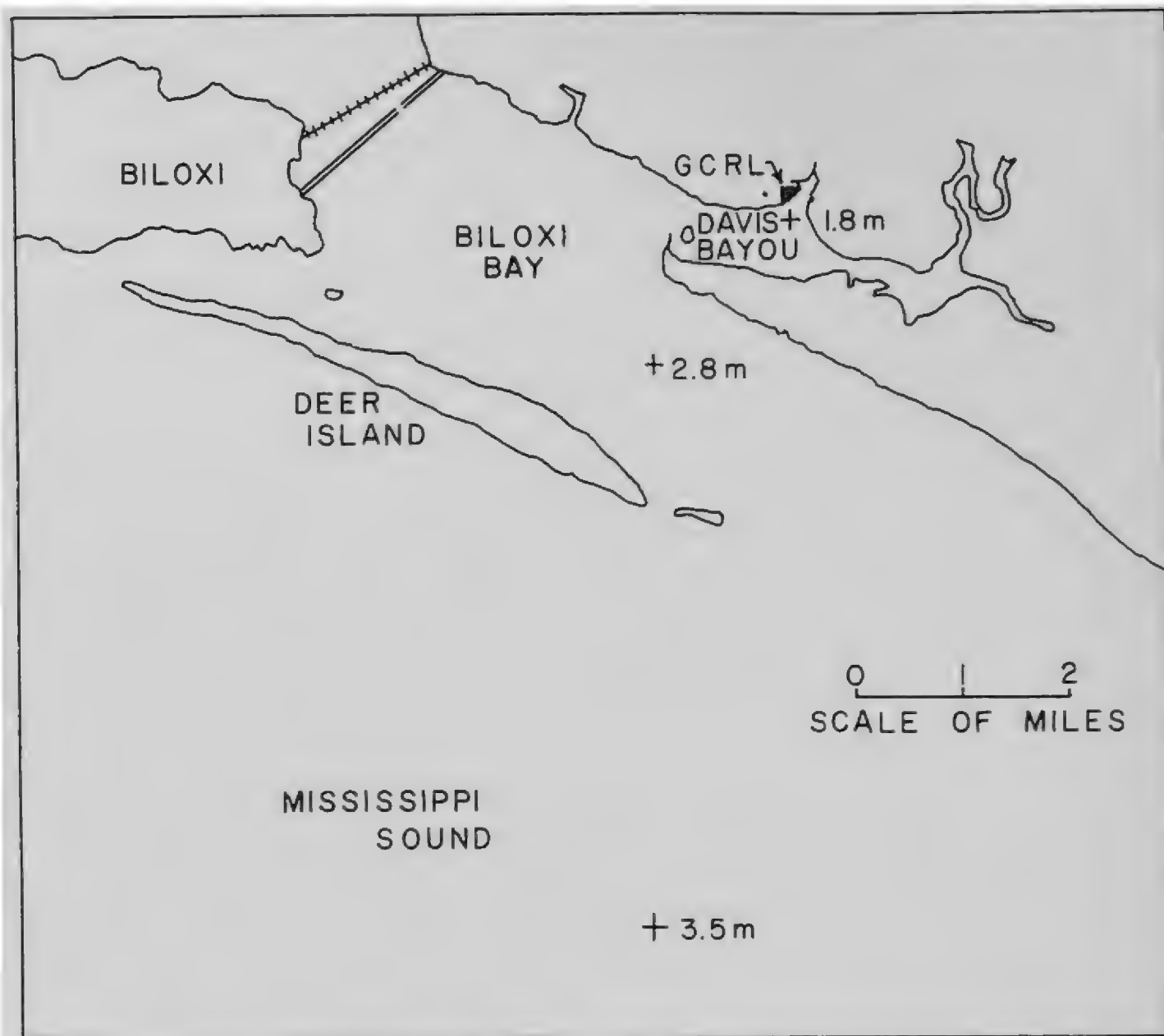


FIG. 1. The area of investigation. The Bayou, Bay and Sound stations are marked by crosses. The location of the Gulf Coast Research Laboratory (GCRL) is indicated.

Methods

FIELD AND LABORATORY PROCEDURES

From mid-June through July, 1955, plankton collections and hydrographic measurements were made at 3 locations along a salinity gradient in Mississippi coastal waters (see Fig. 1). Determinations were made of temperature, salinity, dissolved oxygen and dissolved orthophosphate at suitable depth intervals. Secchi disc readings were made at all stations.

Oxygen determinations were made by the Winkler method. Orthophosphate determinations were made colorimetrically by the stannous chloride method given in Standard Methods for the Examination of Water and Sewage (1946). The high concentration of suspended particles in the water made it usually necessary to filter the samples. In view of the concentration of a yellow dissolved substance in the water, the filtered sample was compared colorimetrically to a distilled water reagent blank before and after treatment with reagents. The difference between the readings was taken as a measure of the phosphate concentration. A 4-inch white Secchi disc was used for transparency measurements.

At first, samples for plankton analysis were collected by pouring a known volume of water through a No. 12 net. This procedure proved to be impractical because the small quantity of plankton present was inadequate for statistical study. Later plankton collections were made by pulling the net horizontally through the water about 16 meters. If the net were 100% efficient, a 16 meter drag would sample about 700 liters of water. The per cent efficiency of the net has been estimated by employing both of the above methods at the same time and found to be about 50%.

Many of the samples were further concentrated in the laboratory prior to counting. An aliquot, usually about 0.09 ml, of each sample was placed on a slide and a coverslip added. The mount was sealed with fingernail polish to prevent drying. Counts were made and the numbers counted translated to numbers per liter.

Six species of *Rhizosolenia* have been encountered in the study. Two of these, *R. alata* and *R. setigera* were sufficiently numerous to permit an evaluation of distribution. *R. alata* was probably the more numerous and was certainly of more general occurrence. *R. alata* is a rather variable species made up of the type and 3 forms. In this study the type and 2 forms (*gracillima* and *indica*) have been encountered. Form *gracillima* was very common while form *indica* was relatively scarce. The distinction between form *gracillima* and the type is one of cell diameter. The cell diameter of the type varies from 7–18 microns and that of form *gracillima* is 7 microns or less according to Cupp (1943). Since measurements of cell diameters do not show a clear-cut separation between form *gracillima* and the type, all *R. alata* having a cell diameter of 3–15 microns have been designated simply as *R. alata*. This procedure is consistent with the approaches of Schütt (1886) and Wimpenny (1936) and consistent with the findings of Margalef (1957). In this paper, then, all reference to *R. alata* excludes form *indica*, which is distinct and is considered separately.

STATISTICAL PROCEDURES

For each sample either 100 cells were counted or cell counts were continued until 0.16% of the sample had been counted. The criterion of counting 100 individuals of a given species was established by Winsor and Walford (1936) and has been used by Winsor and Clarke (1940). The criterion of counting 0.16% of the sample provides that the mean percent deviation from the mean of 10 successive counts will be 12% for population densities of about 90,000 per liter (Littleford, Newcombe and Shepherd, 1940). The value of 0.16% is derived from their data for a counted volume of 0.024 ml from a concentrated sample of 15 mls. The population densities encountered here are considerably lower than 90,000 per liter, which was the lowest density given by Littleford, et al. (1940); however, the duplicate aliquots examined in order to count 0.16% of the sample were in good agreement.

Since many of the *Rhizosolenia* were broken in half and often only one valve was visible in the area being counted, the valves were counted and this number was divided by two to get the number of cells counted.

The chi-square test was used to determine whether or not two cell-diameter frequency distributions represented samples of the same or different populations. The linear correlation coefficient was employed to determine the extent to which two cell-diameter frequency distributions were similar.

In the chi-square comparison the following procedures were employed:

1. When single samples were being compared, the actual number counted in each cell diameter was used in the usual "observed" column. The corresponding values of the "expected" column were obtained by multiplying the numbers counted in each cell diameter by a factor which would make the total of the expected column equal to the total of the observed column. An example of a chi-square calculation of this type is shown in Table 1.

2. When cell-diameter frequency distributions were combined, the average number per liter was determined for each cell diameter and then these values were multiplied by a factor which, in the case of the observed column, would make the total number equal to the total number counted in all the samples involved in the combination; and in the case of the expected column, would make the total number equal to the total number in the observed column. An example of a chi-square calculation of this type is shown in Table 2.

3. When the expected frequency was less than 5 for a cell diameter, diameter classes were combined.

4. In order to make all comparisons comparable, the sample in which the smaller number was counted was placed in the observed column.

If the chi-square value was less than the value at the 0.05 or 5% probability level in the "Accumulative Distribution of Chi-square" table (Snedecor, 1956), the two samples being compared were considered to be components of the same population. If the chi-

TABLE 1

Chi-square calculation for the comparison of the cell-diameter frequency distributions of the *Rhizosolenia alata* populations sampled on June 18 in the Sound at the surface (MS-S) and on June 23 in the Bay at the surface (BB-S). O = observed, E = expected, d.f. = degrees of freedom, P = probability of a higher chi-square value being obtained from two samplings of the same population

June 18 MS-S vs. June 23 BB-S
47.0 cells measured from the June 18 MS-S sample
85.0 cells measured from the June 23 BB-S sample

Cell-diameter in microns	0 June 18 MS-S # measured	June 23 BB-S # measured	June 23 BB-S x 0.553 E	O-E	(O-E) ²	(O-E) ² E
3	17.0	23.5	13.0	4.0	16.00	1.231
4	4.5	16.0	9.0	-4.5	20.25	2.250
5	6.0	15.5	8.5	-2.5	6.25	.736
6	11.5	21.0	11.5	.0	.00	.000
7	1.5	0.5	.5	.....	.....	.....
8	2.0	3.5	2.0	.....	.....	.....
9	1.5	1.5	1.0	.....	.....	.....
10	.....	2.0	1.0	.....	.....	.....
11	0.5	0.5	.5	.....	.....	.....
12	2.0	1.0	.5	.....	.....	.....
13	.....	.....	.....	.....	.....	.....
14	0.5	.....	.....	.....	.....	.....
7-14	8.0	9.0	5.0	3.0	9.0	1.800
Total	47.0	85.0	47.0	.....	.....	6.017

$$\text{Factor: } \frac{47.0}{85.0} = 0.553$$

For d.f. = 4 and for P of 0.05, $\chi^2 = 9.49$; $6.02 < 9.49$; therefore, these samples are from the same population.

For χ^2 of 6.02, $P = 0.20$ or 20%.

TABLE 2

Chi-square calculation for the comparison of the cell-diameter frequency distribution of *Rhizosolenia alata* populations A and B. The derivations of populations A and B are given. MS-B = Sound at the bottom, BB-B = Bay at the Bottom. Other abbreviations are the same as in Table 1

$$A = \frac{\frac{\text{June 18 MS-S} + \text{June 18 MS-B}}{2} + \text{June 23 BB-S}}{2}$$

$$B = \frac{\text{July 8 BB-S} + \text{July 8 BB-B}}{2}$$

A total of 166.0 cells measured from population A
A total of 88.5 cells measured from population B

Cell-diameter in microns	B #/L	O 88.5 B x $\frac{88.5}{282}$	A #/L	E 88.5 A x $\frac{88.5}{533}$	O-E	(O-E) ²	$\frac{(O-E)^2}{E}$
3	118	37.0	176	29.0	8.0	64.0	2.205
4	50	15.5	73	12.0	3.5	12.25	1.02
5	48	15.0	81	13.5	1.5	2.25	.167
6	39	12.0	131	21.5	-9.5	90.25	4.195
7	5	1.5	9	1.5	-0.5	.25	.05
8	9	3.0	20	3.5			
9	5	1.5	16	2.5			
10	4	1.5	7	1.0			
11	---	---	4	.5	-2.5	6.25	.893
12	4	1.5	14	2.5			
13	---	---	---	---			
14	---	---	2	.5			
Total	282	88.5	533	88.0	---	---	8.53

For d.f. = 5 and for P of 0.05, $\chi^2 = 11.07$; $8.53 < 11.07$; therefore, these samples are from the same population.

For χ^2 of 8.53, $P = 0.13$ or 13%.

square value was greater than the value at the 0.05 probability level, the two samples being compared were considered as different populations. For each cell-diameter frequency distribution comparison made in the discussion, the percent probability of a higher chi-square value being obtained from two samplings of the same population is given. The similarity of the two frequency distributions is, then, directly proportional to the probability value.

Physico-Chemical Data

The salinities at the surface and at the bottom in the Sound, Bay and Bayou are shown in Fig. 2 and the density profiles are shown in Fig. 3. The salinities encountered varied from 14.5 to 28.8 ‰. The water column was stratified in the latter part of June, mixed in early July, stratified on July 23 in the Bay and then mixed again on July 31 in the Sound.

Fresh-water discharge into Biloxi Bay has been estimated by adding the flows recorded for the Biloxi and Tchoutacabouffa Rivers (Fig. 4). The discharge of the Biloxi River was measured at Wortham, Mississippi, and the Tchoutacabouffa discharge is taken from a gauge located on Tuxachanie Creek near Biloxi. Tuxachanie Creek is a tributary

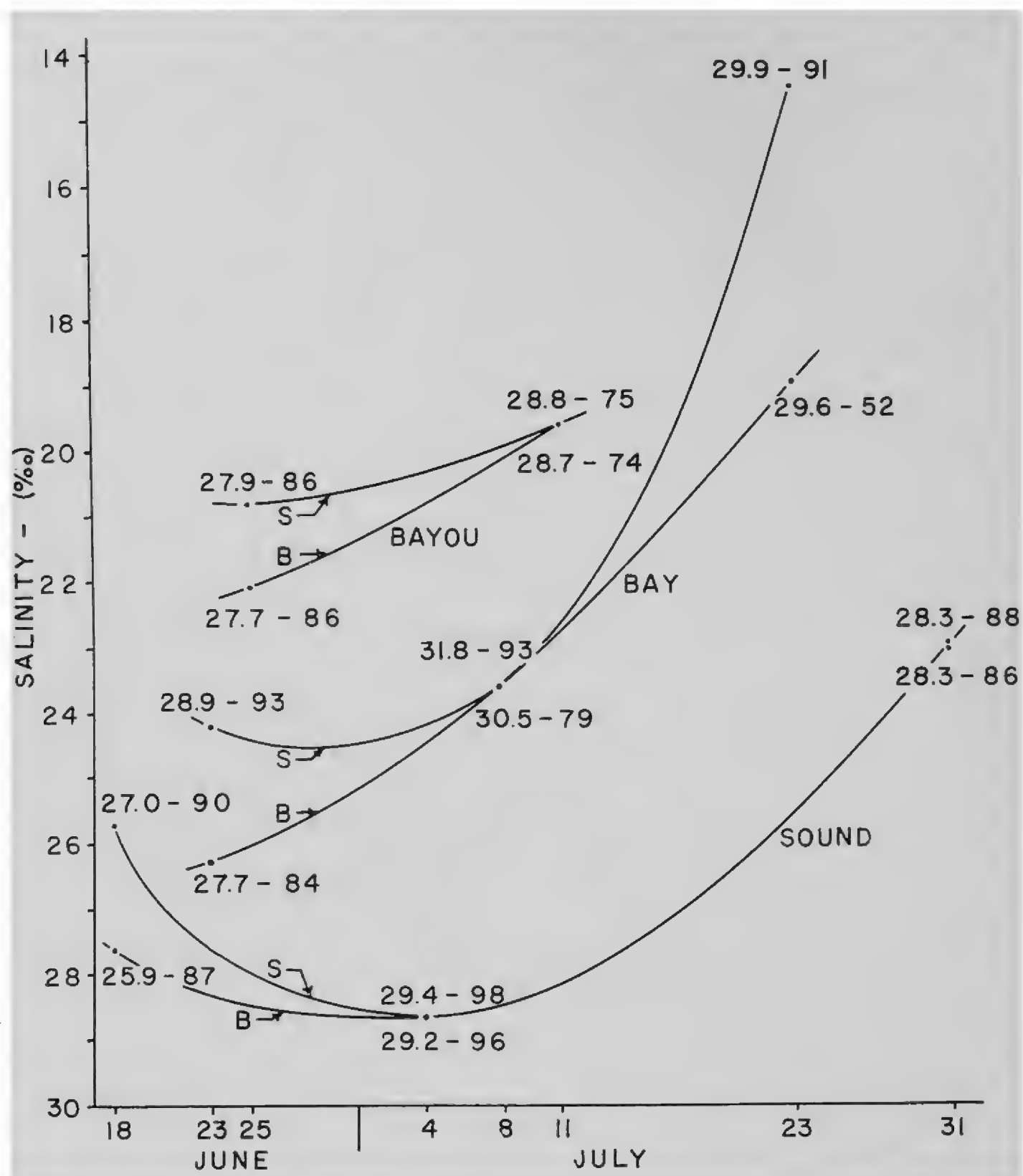


FIG. 2. Salinity, temperature and percent saturation of dissolved oxygen at the surface (S) and near the bottom (B) in the Bayou, Bay and Sound. The temperature in degrees Centigrade (left) and the dissolved oxygen in percent saturation (right) are shown above the salinity curve in the case of surface data and below the salinity curve in the case of bottom data.

of the Tchoutacabouffa River. There was very little fresh water entering the Bay until about the tenth of July when a period of substantial fresh-water discharge began.

In Fig. 2 the temperature (left) and the percent saturation (right) of oxygen are given for the surface and bottom on each sampling date. The Sound was cooler and had a higher percent saturation of oxygen than the Bay. The values for the Bayou do not show the variation which one would expect. More frequent sampling might have produced a much wider range here.

The maximum oxygen saturation encountered was 98% and coincided with the maximum salinity encountered and also with the maximum diatom concentration, which was

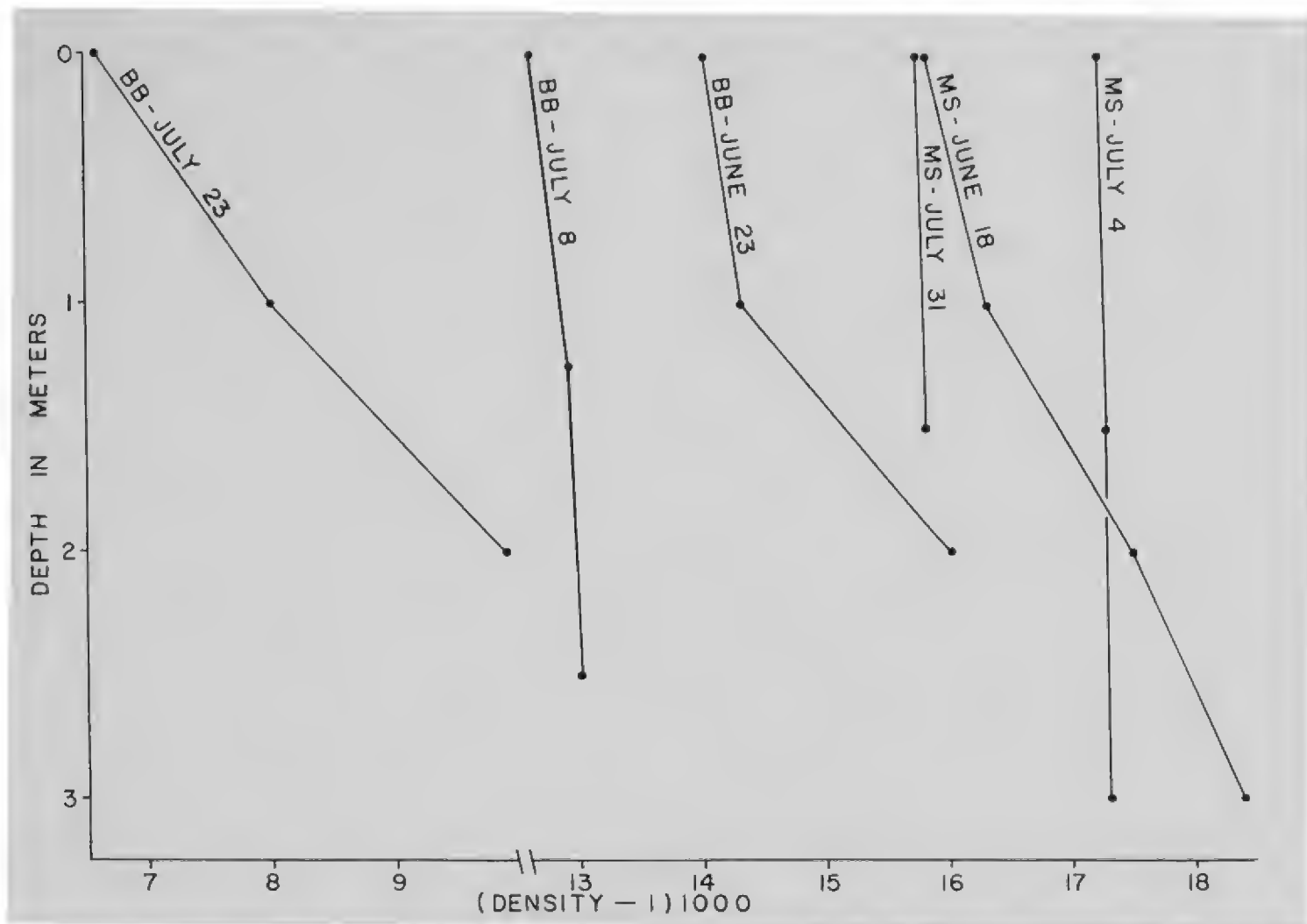


FIG. 3. The vertical distributions of density for Mississippi Sound (MS) and Biloxi Bay (BB) on the dates indicated.

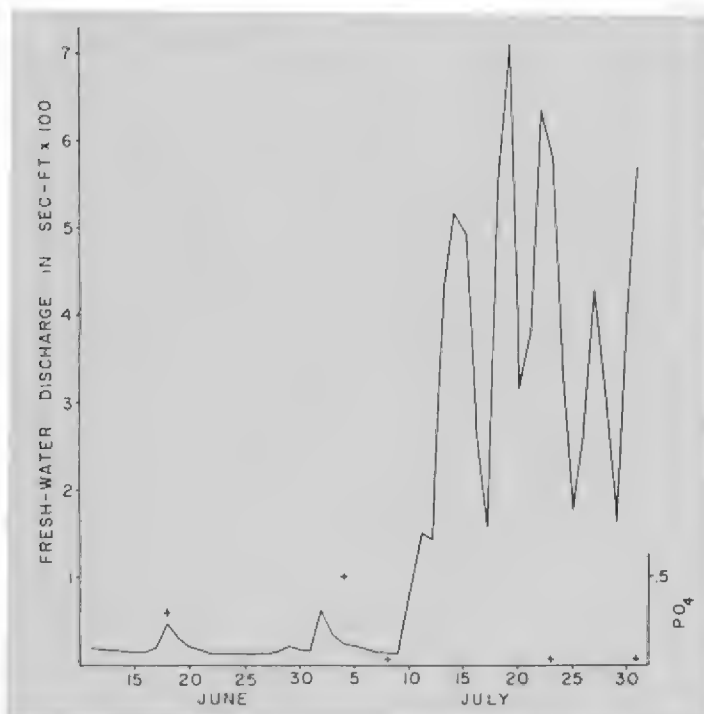


FIG. 4. A daily record of fresh-water discharge in hundreds of second-feet into Biloxi Bay from the Biloxi and Tchoutacabouffa Rivers. The discharge of the Biloxi River was measured at Wortham, Mississippi, and the Tchoutacabouffa discharge is based upon a gauge located at Tuxachanie Creek, which is a tributary of the Tchoutacabouffa. Average phosphate concentrations for the water column in Biloxi Bay and Mississippi Sound are indicated by crosses and expressed as microgram-atoms per liter.

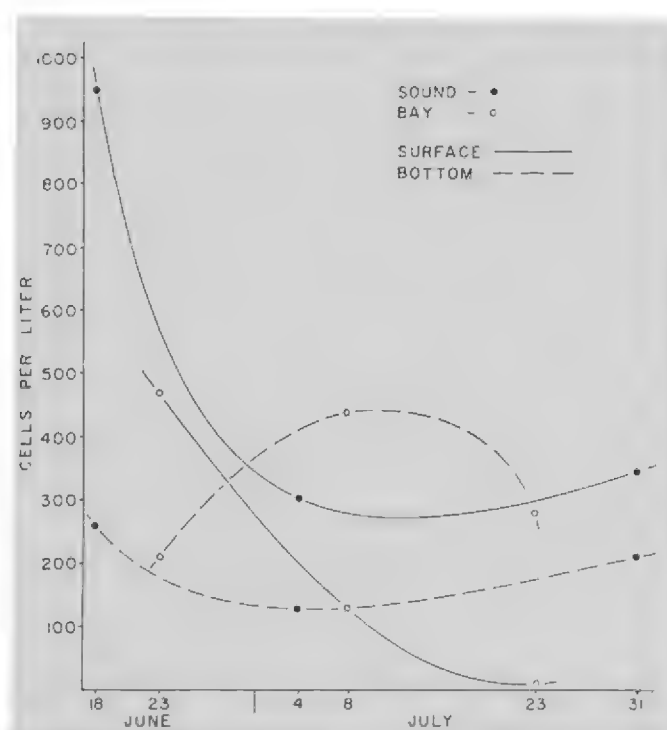


FIG. 5. The surface and bottom concentrations of *Rhizosolenia alata* in Mississippi Sound and Biloxi Bay.

made up very largely of *Skeletonema costatum*. The minimum oxygen saturation was 52% and occurred at the minimum bottom salinity encountered.

The PO_4 values (Fig. 4) were quite low, frequently zero, and when the reading was positive it was open to some question because the typical blue color almost never occurred. The greatly increased river discharge in mid and late July did not bring about an increase in the phosphate content of the water in the Bay and Sound. The phosphate concentration was zero before the discharge began and was zero during the discharge. The Secchi disc readings varied from 38 to 107 cm.

Dispersal of *Rhizosolenia alata*

The concentrations of *Rhizosolenia alata* in the surface and bottom waters of the Sound and Bay are shown in Fig. 5. The maximum concentration of 948 cells per liter was encountered at the beginning of the study period on June 18 at the surface in the Sound. Cell-diameter frequency distributions are shown for the samples taken in Sound surface waters (Fig. 6), Sound bottom waters (Fig. 7), Bay surface waters (Fig. 8), and the Bay bottom waters (Fig. 9).

POPULATION GROUPINGS

The June 18 maximum (Fig. 6) is characterized by peaks of 3-micron and 6-micron cells. There are two other samples which show a 3-micron and 6-micron peak. These are the samples taken on June 18 at the bottom in Mississippi Sound and on June 23 at the surface in Biloxi Bay with the concentration of the former being 260 cells per liter and that of the latter being 458 cells per liter. It is accordingly assumed that the bloom was centered in the Sound and extended into the Bay, where it was developed to about one-half the concentration found in the Sound. A chi-square test clearly indicates that the

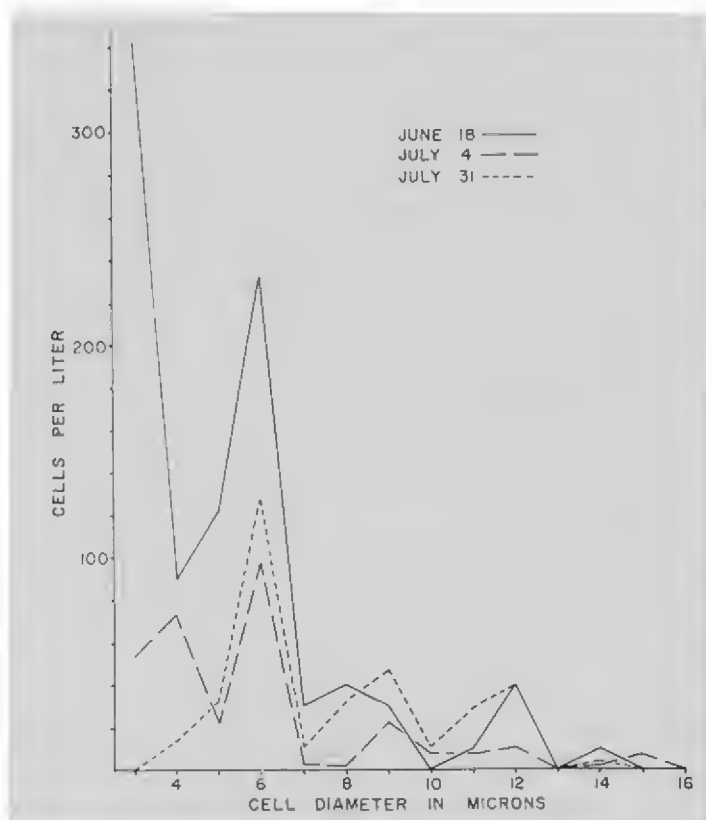


FIG. 6. Cell-diameter frequency distribution of the *Rhizosolenia alata* populations sampled in the surface waters of Mississippi Sound on the dates indicated.

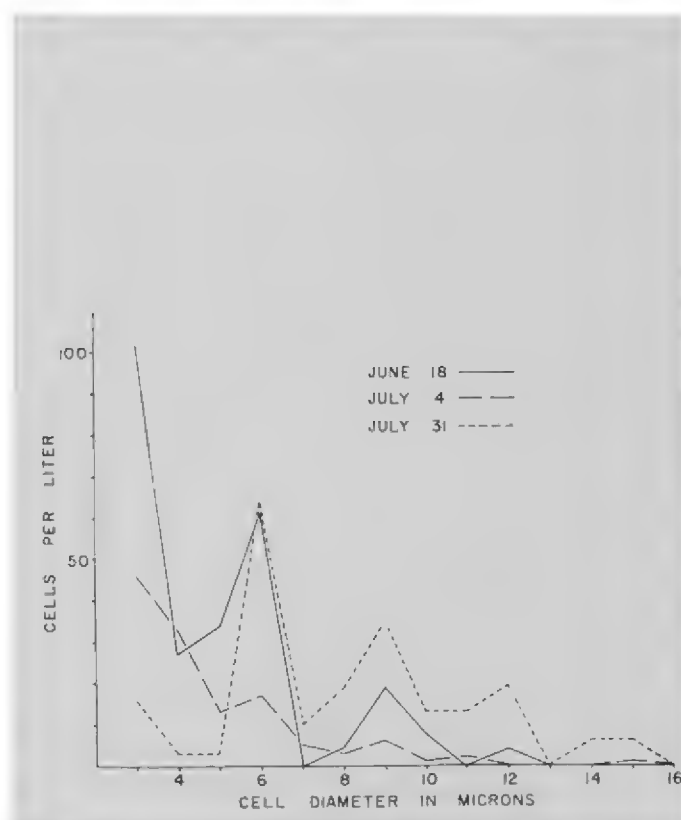


FIG. 7. Cell-diameter frequency distributions of the *Rhizosolenia alata* populations sampled in the bottom waters of Mississippi Sound on the dates indicated.

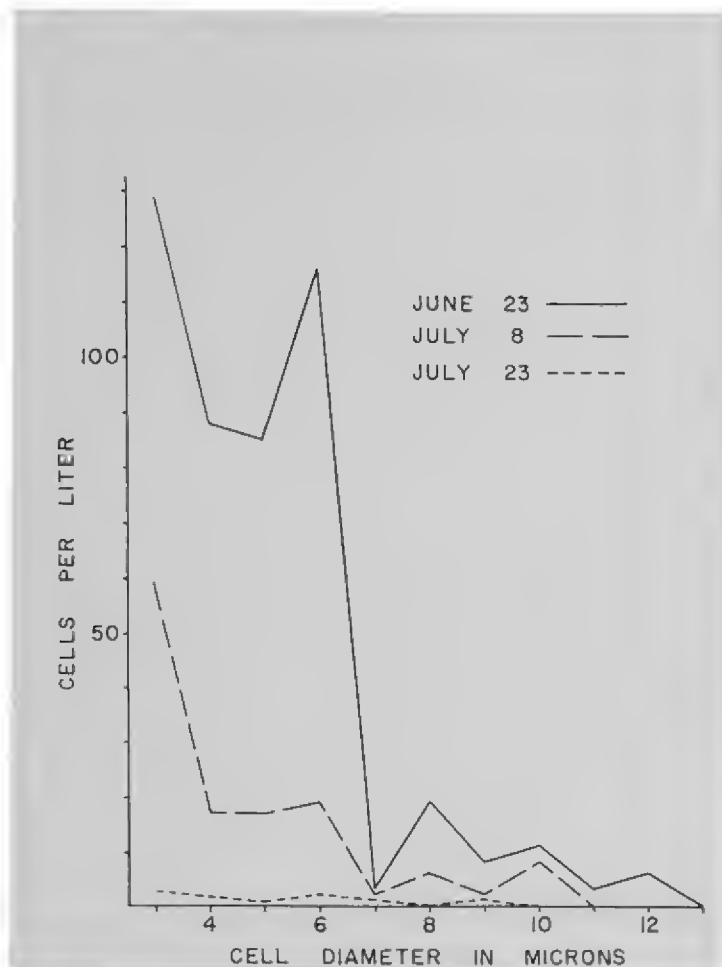


FIG. 8. Cell-diameter frequency distributions of the *Rhizosolenia alata* populations sampled in the surface waters of Biloxi Bay on the dates indicated.

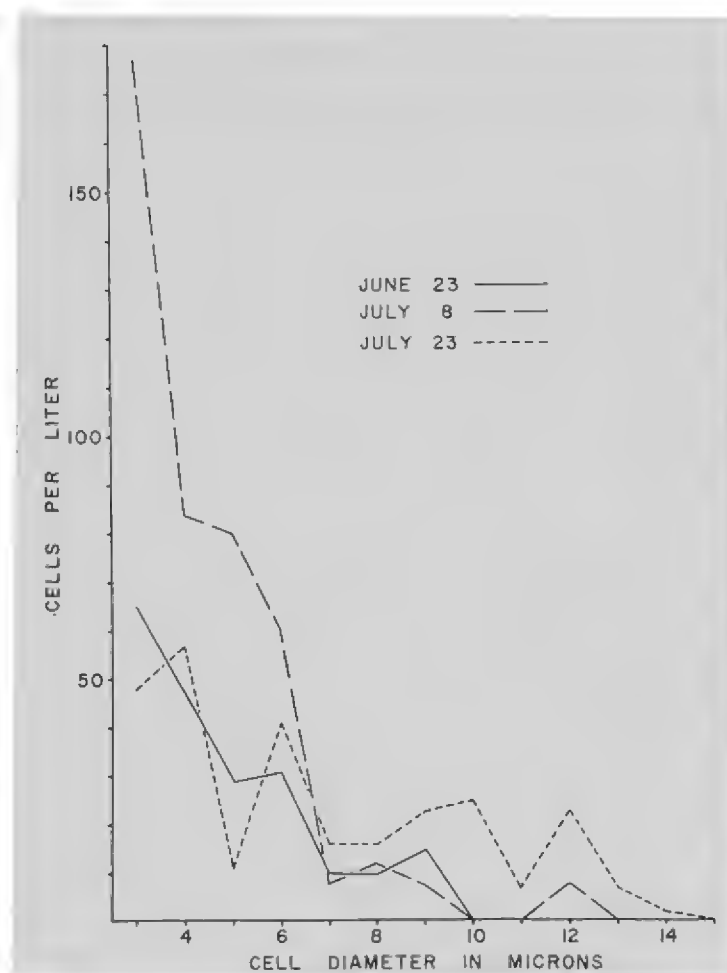


FIG. 9. Cell-diameter frequency distributions of the *Rhizosolenia alata* populations sampled in the bottom waters of Biloxi Bay on the dates indicated.

samples taken at the surface and bottom in the Sound on June 18 are from the same population (92% probability of a higher value). The chi-square test also indicates that the June 23 Bay surface population is the same as that encountered on June 18 at the surface in the Sound (25% probability of a higher value). These three samples, then, are assumed to have been taken from one population, which is hereafter referred to as population A. The frequency distributions of these three samples have been averaged to give a frequency distribution for population A (Fig. 11).

The 3-micron cells steadily disappear from the surface waters of the Sound and by the end of July are entirely gone (Fig. 6). There are two samples in the Bay, other than the June 23 sample, which show frequency distributions having a predominance of the 3-micron cells. These are particularly the bottom, but also the surface sample of July 8 (Figs. 8 and 9). A chi-square test indicates that the samples taken at the surface and bottom in the Bay on July 8 represent one population (53% probability of a higher value), which is hereafter referred to as population B (Fig. 11).

The 6-micron cells are largely restricted to the Sound, and are a particularly important part of the July 31 samples. Since the physical and chemical data indicate that the water column was mixed in the Sound on July 31 (Figs. 2 and 3) and since a chi-square test indicates that the samples taken at the surface and bottom in the Sound on July 31 are from the same population (57% probability of a higher value), these surface and bottom populations have been combined to give an average size frequency distribution hereafter referred to as population C (Fig. 12).

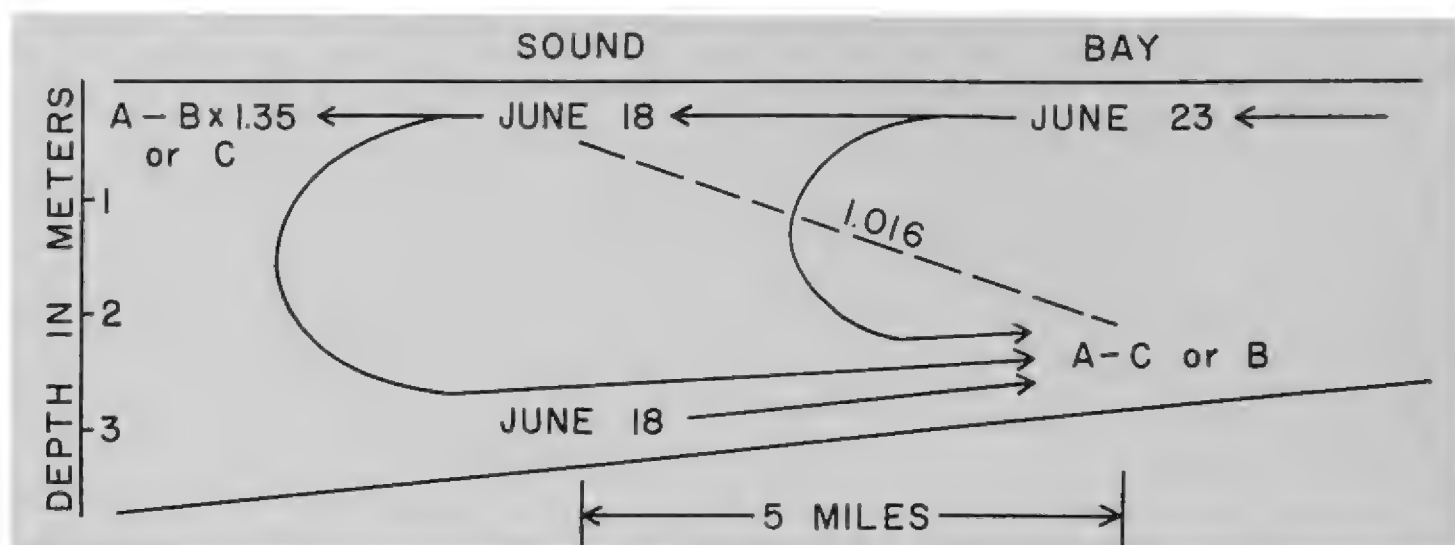


FIG. 10. A diagrammatic section along the salinity gradient with the locations of the Bay and Sound stations and the presumed transport of the three components of population A (the surface and bottom samples in the Sound on June 18 and the surface sample in the Bay on June 23) indicated. The late June locations of these three components are indicated by the dates and the presumed transport indicated by the arrows. The 1.016 isopycnal for the late June period is shown by a dashed line. The presumed location of derived population A-C or B is indicated for early July just prior to vertical mixing. The origin of population (A-B $\times$ 1.35) or C is indicated. See the text for further explanation.

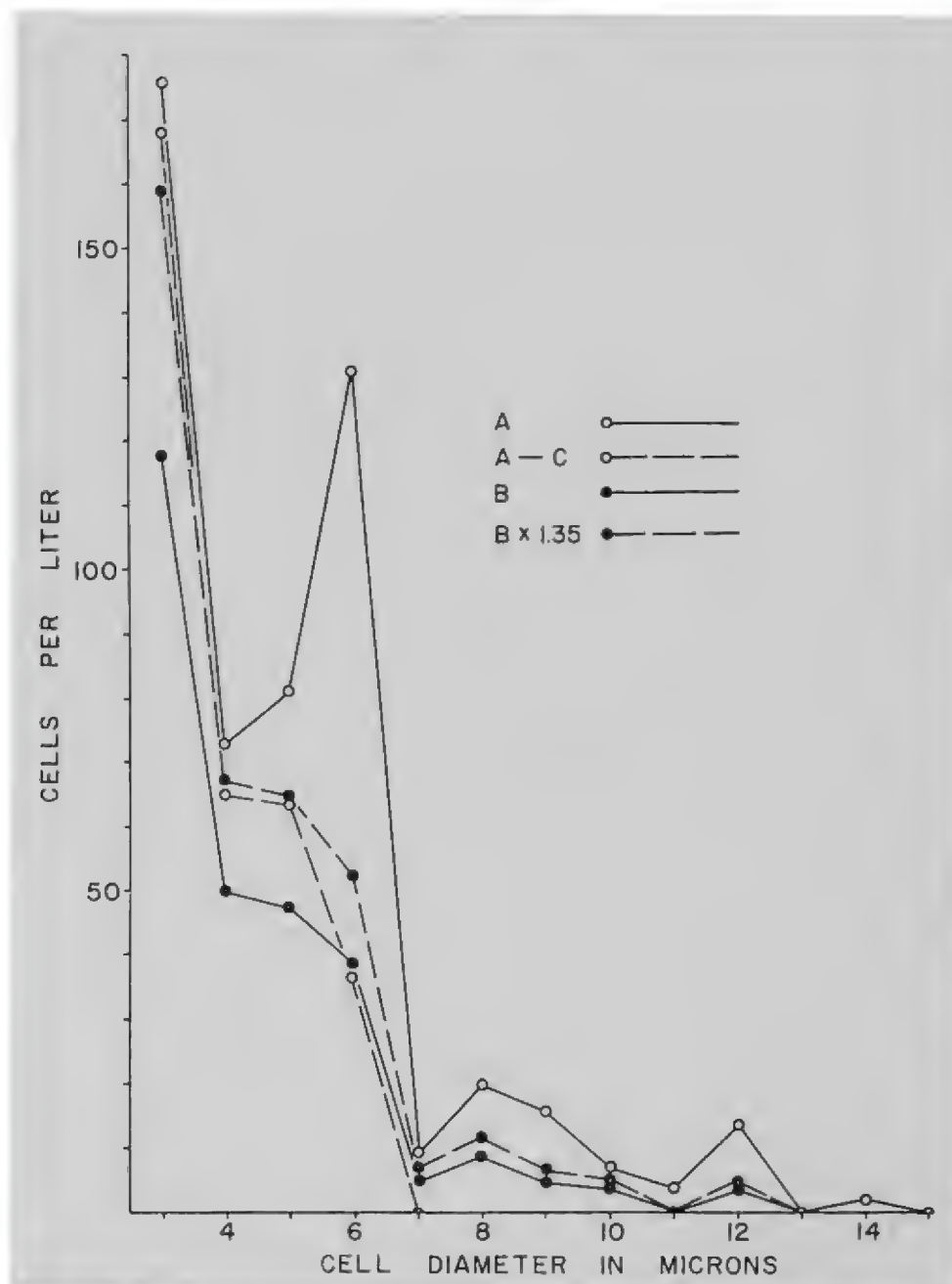


FIG. 11. A comparison of the cell-diameter frequency distributions of 4 derived *Rhizosolenia alata* populations. See the text for the derivation of these populations.

DISPERSAL PATTERN

A dispersal pattern for population A may be proposed if one assumes the usual estuarine two-layered circulation in conjunction with a more rapid settling of the narrower cells. The narrower, particularly the 3-micron, cells of population A are assumed to have settled into the bottom waters and to have been transported into the Bay to make up a significant part of population B (Fig. 10). The frequency distribution of populations A and B are in general similar ($r = 0.94$: 13% probability of a higher chi-square value), but the July 8 curve shows fewer cells in every diameter suggesting a loss of cells during transport into the Bay (Fig. 11). The concentrations in each cell diameter for the population B curve have been multiplied by 1.35 so that the relative differences between the two distributions may be more clearly seen (Fig. 11). A comparison of $B \times 1.35$ with A shows that population A is markedly different from population B only in the case of the 6-micron cells, which are much more numerous in population A. This difference suggests that the 6-micron cells are not settling out as rapidly as the other cells; an inference which may also be drawn from the surface Sound samples (Fig. 6).

If one subtracts derived population $B \times 1.35$ from population A, the difference should be that part of population A which did not sink and move into the Bay. This derived population ($A - B \times 1.35$) shows a great deal of resemblance to population C. Population C is compared to population ($A - B \times 1.35$) in Fig. 12, where the agreement is seen to be fairly good. The correlation coefficient of 0.90 indicates considerable similarity although the chi-square value is high enough ($< 0.5\%$ probability of a higher value) to indicate that the two populations are not the same. The main difference between the two curves is found in the numbers of cells of larger diameters found in population C. These larger cells have almost certainly been brought into the area from farther out the salinity gradient and it is the addition of these larger cells which has caused the high chi-square value.

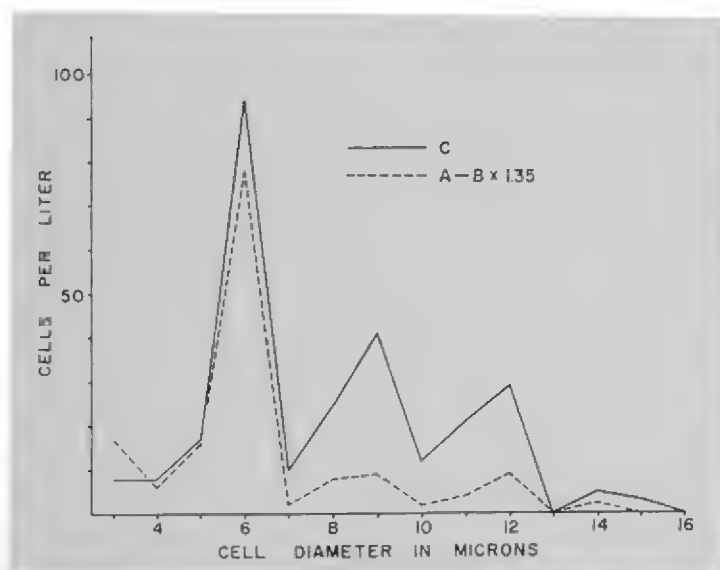


FIG. 12. A comparison of the cell-diameter frequency distributions of 2 derived *Rhizosolenia alata* populations. See the text for the derivation of these populations.

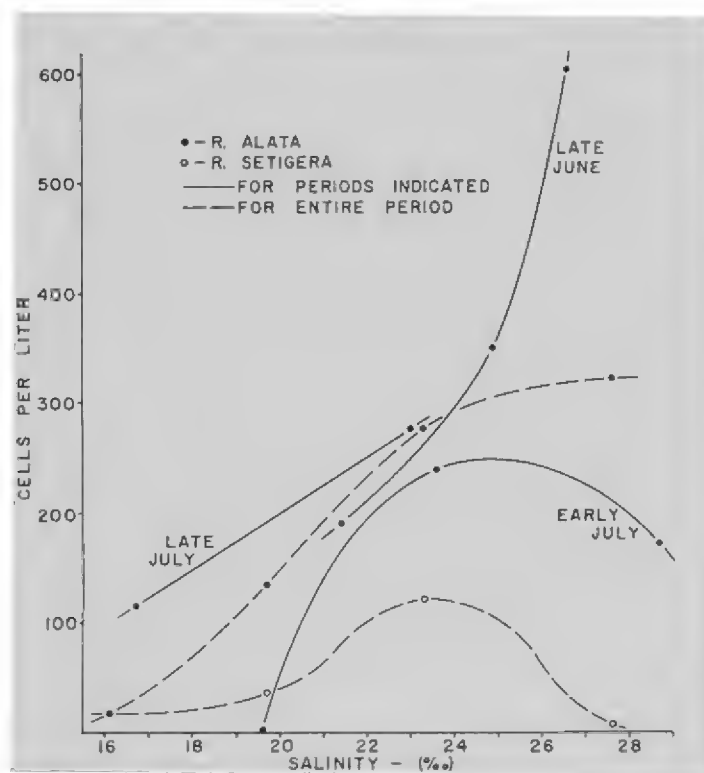


FIG. 13. The average concentrations of *Rhizosolenia alata* and *Rhizosolenia setigera* in relation to salinity are shown for the entire investigation period in dashed lines. The average concentrations of *R. alata* in relation to salinity are shown for late June, early and late July in solid lines.

It is possible to remove these larger cells which are presumed to have been added from farther out the salinity gradient by subtracting the size frequency distribution expressed in numbers per liter of population C from the size frequency distribution of population A. When the subtraction for any size class yields a negative difference, this difference is said to be zero. The resultant population ($A - C$) is seen in Fig. 11, where it may be compared to $B \times 1.35$. Even though the two curves are quite similar ($r = 0.99$), the chi-square value is still high ($< 0.5\%$ probability of a higher value). However, 88% of the chi-square value is derived from the last size interval of 6 to 12-micron cells. If one restricts the comparison to the cell sizes found in the ($A - C$) population; that is, 3-micron to 6-micron, the chi-square value is quite low with a 74% probability of a higher value.

It therefore seems reasonable to accept the hypothesis that population B represents the fraction of population A which is sinking and being moved in a landward direction in the bottom waters and population C represents the fraction of population A which is not sinking and is being moved in a seaward direction in the surface waters (see Fig. 10).

This line of reasoning accounts for all but the July 4 Sound and July 23 Bay populations. The July 4 Sound surface sample shows most resemblance to the Bay surface sample of June 23 ($r = 0.87$), but a chi-square test indicates that they are not the same population (0.5% probability of a higher chi-square value). The July 23 bottom sample, where the concentration is much higher, shows most resemblance to the surface Sound population of July 4 ($r = 0.83$).

SETTLING

Riley, Stommel and Bumpus (1949) have reviewed the literature on the sinking rate of diatoms and find that this rate may vary from 0.6 meters per day to 30 meters per day. They further state that "it is generally not clear whether the phenomenon represents the sinking of a senescent population that has become less buoyant or is a normal process accompanying an increase in the stability of the water." On the other hand, Gross and Zeuthen (1948) have found that under suitable conditions planktonic diatoms do not sink and contend that usually planktonic diatoms have a specific gravity equal to that of sea water. However, they add that "exceptionally narrow cells of *Ditylum* seem to lose their buoyancy." More recent experimental work of Steele and Yentsch (1960) has shown that older cells settle faster than do rapidly growing cells. Furthermore, when old cells are enriched in the dark, the settling rate is considerably reduced. Thus, the findings of Gross and Zeuthen, as well as those of Steele and Yentsch, are consistent with the postulation presented in this paper; namely, that the very narrow, 3-micron, *R. alata* cells are settling out while the larger cells, especially the 6-micron cells, remain near the surface or at least settle only very slowly.

OTHER CONSIDERATIONS

The cell-diameter frequency distributions show no evidence of a reduction in diameter due to division during the study period. This is to be expected for the following reasons: (1) Schütt's (1886) data for this species in the Baltic indicate that about three months was required for the diameter to be reduced by one micron, i.e. from about 4.5 to 3.5 microns, and; (2) a low concentration of diatoms in a post-bloom condition should not be dividing rapidly.

The question of selective feeding as a possible mechanism for controlling size has not been resolved; however, Curl and McLeod (1961) found that copepods feeding in a plankton sample of various diatoms would leave the *Rhizosolenia* uneaten. The probability of a two-layered circulation may be judged from the density profiles (Fig. 3) and the position of the 1.016 isopycnal (Fig. 10).

Distribution in Relation to Salinity

The collected data permit one to relate concentration of the species of *Rhizosolenia* to salinity.

The average concentrations of *Rhizosolenia alata* over the entire period of collection were 354 cells per liter for the Sound, 246 cells per liter for the Bay and 62 cells per liter for the Bayou. There was accordingly a regular decrease in the concentration landward. The average concentration of *R. alata* as it is related to the average salinities in the Sound, Bay and Bayou for the periods of late June, early July, late July and for the entire period is shown in Fig. 13.

The average concentrations of *Rhizosolenia setigera* over the entire collecting period were 45 cells per liter for the Sound, 119 cells per liter for the Bay and less than 1 cell per liter for the Bayou suggesting that this species is best able to tolerate and develop in the conditions existing in the Bay. The distribution along the salinity gradient for the entire period is shown in Fig. 13.

Rhizosolenia stolterfothii exhibited a distribution pattern which was very similar to that of *R. setigera*. It was most abundant in the Bay on July 8 when the salinity was 23.6 ‰ and was not abundant in the Sound or Bayou. The other species or forms encountered were *R. alata* form *indica*, *R. calcar-avis*, *R. imbricata* variety *shrubsolei* and *R. robusta*. These were never numerous, but all had their maximum concentrations in the higher salinities of the Sound.

COMPARISON TO OTHER AREAS

R. alata is generally considered to be oceanic (Gran, 1905; Hustedt, 1930; Cupp, 1943; Freese, 1952; Curl, 1959); however, Gran points out that form *gracillima* is found near the coast; Hustedt, that the narrower cells (here he seems to be referring to the type and forma *gracillima*) are found more in the coastal areas and Cupp, that the type, though oceanic, is often near the coast and that forma *gracillima* is a coastal form, perhaps truly neritic. Curl states that *R. alata* is the most important diatom in Apalachee Bay.

Bandel (1940) states that in the Darss Sill area of the Baltic *R. alata* occurred just at the time of the salinity maximum in the summer and then disappeared again with a decrease in salinity. He points out that several other persons working in the same general area have shown this distribution pattern for *Rhizosolenia* species in general. Bandel also found that *R. alata* came into the area in the bottom waters derived from farther out the salinity gradient and then at the Sill may, by upwelling or mixing, be brought to the surface where a bloom may ensue. One well-defined maximum of this species occurred in the Sill area early in August when the local salinities ranged from 15 ‰ to 22 ‰. The numbers during this maximum ranged from 11,600 to 21,400 cells per liter. The actual salinity range encountered by Bandel on the Sill was 9 ‰ to 31 ‰.

Prasad (1954), working in the Gulf of Mannar, where the salinity monthly averages ranged from 28.8 to 36.4 ‰, found that *R. alata* showed its maximum development (a

well-defined pulse during which time it was the dominant organism) in March when the salinity was 30.8 ‰. Davis (1950) has classified this species as common at locations of 8 and 16 miles from the coast in the Gulf of Mexico and finds it less abundant at his in-shore station as well as at his more seaward stations. Grøntved and Steeman Nielsen (1957) stated that in the Kattegat and the Belt Sea *R. alata* is a constantly occurring summer and autumn form which may develop high maxima. Wimpenny gives no quantitative data but does record *R. alata* in a state of active auxospore formation in the North Sea where the salinity was 34.8 ‰.

Thus, *R. alata* appears to be oceanic, but it occurs, often quite abundantly, near the coast and further, the narrower cells are predominant in coastal areas. The relationship between the concentration of *R. alata* and salinity found in this study is consistent with these views.

The cell diameter of this species in the Sound and in the Bay is shown in Fig. 14. The mean diameter in the Bay was always less than the mean diameter in the Sound.

Auxospore formation, which would influence the size distribution pattern, was never observed in these samples even though hundreds of cells were examined in the course of the analysis. Since the larger cell sizes, particularly those from 7 to 15 microns, were found more abundantly in the Sound, it is logical to assume that auxospore formation is occurring further offshore, perhaps in the Gulf. Wimpenny (1936) has recorded abundant auxospore formation in this species in the North Sea where the salinity was 34.8 ‰. However, Schütt (1886) has recorded auxospore formation in the Baltic where the salinity should have been lower.

R. setigera is generally considered to be neritic. Its distribution in relation to salinity is consistent with this generalization, especially when compared to the distribution of *R. alata*.

Acknowledgments

Acknowledgments are gratefully accorded to Harold Howse, Billy Joe Grantham and

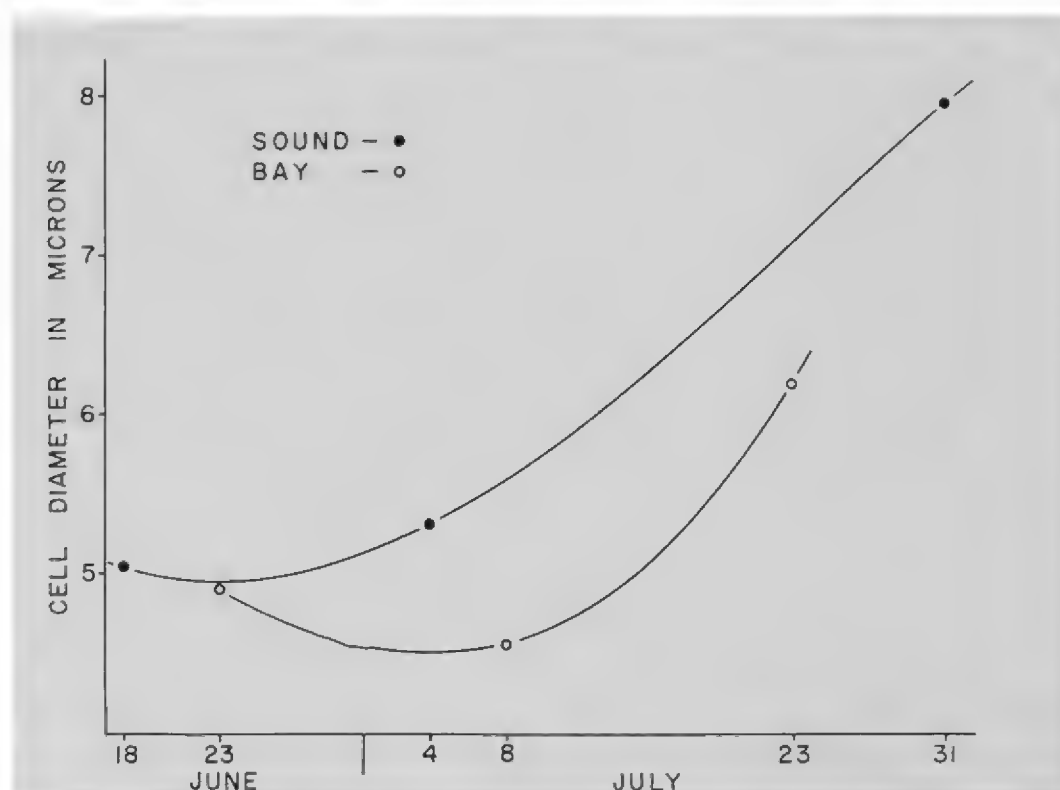


FIG. 14. The average cell diameter in microns of *Rhizosolenia alata* in Mississippi Sound and Biloxi Bay.

Samuel Rosso for assistance with the microscopic analysis, to my wife, Hazel Woodmansee, for assistance with the statistical analysis, to W. H. Robinson of the Geological Survey for the river discharge data, and to J. Fred Walker for his continued interest in the project.

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Distribution of the Zooplankton in the Salt Marshes of Southeastern Louisiana¹

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Abstract

A plankton survey was made at 15 stations in the salt water marshes of southeastern Louisiana from July 1959 to March 1961. The physical and chemical parameters including temperature, oxygen, salinity, turbidity and inorganic phosphate, were measured concurrently.

In the study area, which ranged from nearly fresh to nearly marine waters, one species of copepod, *Acartia tonsa*, dominated the zooplankton with 145,000 per five minute haul and was abundant throughout the year.

There were few other populations. Numerically important copepod species were *Eurytemora hirundoides*, *Pseudodiaptomus coronatus*, *Paracalanus crassirostris*, and *Oithona* spp. Meroplanktonic elements such as nauplii and zoeae of Cirripedia also attained numerical importance.

Fresh water and marine faunas were localized and in minor numbers. A major zooplankton outburst occurred in April 1960. No comparable increase was recorded at any other time. Populations were more numerous in open water than in bayou samples. Smallest numbers were found in October.

Introduction

In 1958 the Corps of Engineers began constructing a ship channel between New Orleans and the Gulf of Mexico across marshes valuable for fisheries resources such as shrimp, crabs, oysters, and food fish, and for fur-bearing animals such as muskrats and nutria. In order to determine the potential effects of the channel on the flora and fauna in the project area, a contract was made between the Fish and Wildlife Service and the Texas A. & M. Research Foundation. Under this contract the Department of Oceanography and Meteorology at the A. & M. College of Texas collected samples of the aquatic fauna to determine natural fluctuations in their distribution and the range of hydrological conditions under which they lived. This plankton survey was part of the overall study. Data on the type and abundance of the plankton in the region were previously nonexistent.

DESCRIPTION OF THE PROJECT AREA

The project area covered some 700 square miles, comprising a complex system of lakes, bayous, and marshland spreading from the almost fresh water of Lake Pontchartrain in the north to the marine conditions of Breton and Chandeleur Sounds to the south. The project area was located in the Mississippi Delta region, east of the river following the alignment of the planned ship channel. The 70-mile long channel starts at a point where it connects with the Inner Harbor Navigation Canal of New Orleans

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(Industrial Canal) and runs almost due east for more than five miles, following the Intracoastal Waterway. From this point the Channel skirts the southwestern shore of Lake Borgne and traverses Bayou La Loutre ridge in a southeasterly direction across the Mississippi Delta to the open Gulf by way of Breton and Chandeleur Sounds (see Fig. 1). The basic geology of the region was investigated by Russell (1936), and Treadwell (1955).

Relative to the land, the water level has been rising steadily in the area (O'Neil, 1949). Three explanations have been offered for this phenomenon: 1) compaction of the sediments; 2) depression of the earth's crust by the sediment load of the river; and 3) the

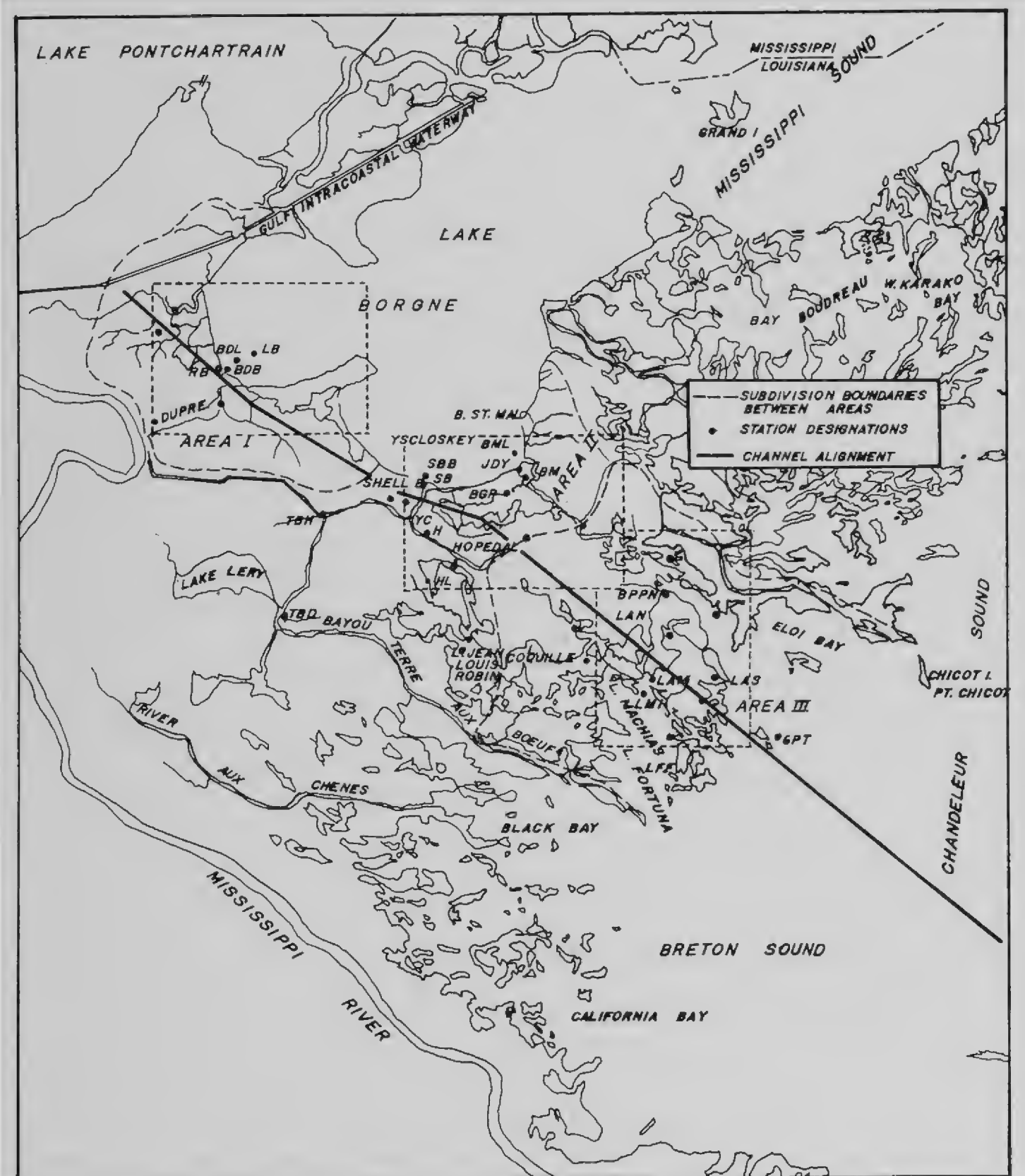


FIG. 1. Chart showing the station locations and boundaries of the three sub-areas in the Mississippi River-Gulf outlet project area.

eustatic change of sea level (Gunter, 1952; and others). The subsidence has been accelerated somewhat by the construction of levees.

The type of vegetation covering the marshland and levees was related to the height of permanent water table. Trees were growing on high land while the lower land supported marsh vegetation (Treadwell, 1955). In general, there was a gradual change in flora from salt water to fresh water habitats. Many plants, however, thrived in several environments and were found in fresh, salt or brackish waters. Further detail on the eastern Louisiana marsh vegetation was given in the works of Penfound and Hathaway (1938).

On the basis of a progressive increase in salinity, the project area was divided into three sub-areas (see Fig. 1) including the nearly fresh waters of Bayou Dupre (sub-area 1), waters of intermediate salinity (sub-area 2), and those of Breton and Chandeleur Sounds (sub-area 3), where nearly marine conditions prevailed. Lakes and bayous were generally less than ten feet in depth. In each sub-area five stations were selected representing lake, bayou, and intermediate conditions.

Materials and Methods

A field laboratory was established at Hopedale, Louisiana, from which the sampling program was conducted. From July 1959 to August 1960, each sub-area was sampled three times a month except for August 1959 when sampling took place only in the first week. No samples were taken in September 1959. From September 1960 to March 1961, each sub-area was sampled twice monthly. Twenty-five to forty-eight samples were taken per station—a total of 617.

FIELD TECHNIQUE

Sampling was effected from the M/V Maggie, a 24-ft cabin cruiser. The zooplankton was collected with a nylon net of standard design with a detachable brass bucket at the cod-end. It had a mouth diameter of 0.50 m and a length of 1.60 m. The netting had a mesh aperture of approximately 0.239 mm (#6). Use of a #8 net was abandoned in favor of the coarser #6 net in an attempt to decrease the amount of suspensoids otherwise present in considerable amount in some samples. Samples in July and October 1959 were obtained with a 0.203 mm (#8) net. All the hauls were of five-minute duration and were made in daylight at the surface from the stern of the vessel. Towing speed was about two knots. At the bayou stations plankton nets usually were towed in the center of the bayous following their contours. At lake stations the hauls were made in a circular pattern. The catch was then preserved in 5 per cent formalin neutralized with borax. No attempt was made to estimate the volume of water that passed through the net. At times, clogging interfered with the proper operation of the net, thus reducing the amount of water filtered. Considerable amounts of detrital material either floating at the surface or in suspension in the water precluded the use of any flow meter. The impeller would not have functioned reliably and erroneous conclusions might have been drawn as to the actual volume of water filtered. Effort was made, however, to keep the towing time and speed as consistent as possible. The net was rinsed with great care between the hauls to prevent contamination of the samples from one station to the next. After the contents of each haul had been emptied in a sampling bottle, the bucket was rinsed with a hose to

detach any organisms trapped in the wire mesh window. The window was subsequently cleaned with a toothbrush to ensure maximum filtering capacity.

During the course of the plankton survey, examination of the net mesh under a microscope revealed a progressive narrowing in the mesh opening due to the slow deposition of organic material. To prevent excessive decrease in mesh size, the net was left soaking overnight at fortnightly intervals in soap suds, rinsed and brushed after complete drying.

LABORATORY TECHNIQUE

Before the enumeration of the sample content, the liquid lying above the zooplankton in the sampling vial was partially poured out. The balance of the sample which contained some liquid and the zooplankton was then transferred to a conical pharmaceutical graduate varying in size from 25 to 250 ml and indicating the sample volume to the nearest ml. The sample was allowed to settle for approximately 30 minutes before the volume was determined.

Few true plankton volumes were obtained because, in many of the samples, detrital material sometimes represented a volume several times that of the actual plankton sample. The volume was thus only an index to the desirable dilution. Proper dilution was obtained after vigorous agitation when one ml of the sample provided approximately 250 organisms. As a check on the dilution factor, a grid of about 64 cm² was placed under the counting dish. After the aliquot was distributed over the counting dish as evenly as possible, a few squares were counted at random. This provided a quick approximation of the total numbers. If the first aliquot gave sufficient numbers, the sample was counted immediately, otherwise more aliquots were added. In those samples where the total number of specimens was less, or only slightly more than 250, all the specimens were enumerated.

The plankton was examined under 20X power. Specimens appearing for the first time were dissected and drawn for future reference after being observed under 470X power. The morphological characteristics were then compared to a model specimen to establish the proper identification. All the copepodites were assigned to a species, a genus, or to a well-defined order or sub-order. No attempt was made to identify the nauplii.

The monographs of Sars (1903, 1918) have been used extensively as taxonomic references. Other references included Wilson (1932a and b), Rose (1933), Pratt (1935), Bückmann (1945), Farran (1948), and Wilson (1958). Pennak (1953) and Ward and Whipple (1959) also were used to identify the fresh water specimens.

HYDROGRAPHIC METHODS

Coincident with each plankton haul, a series of hydrographic samples were taken at the surface and at a depth of five feet for determinations of salinity, dissolved oxygen, inorganic phosphates, pH, and turbidity.

Temperatures were taken at the surface of the water only, from a bucket sample and measured to the nearest 0.1°C.

Salinity observations were determined by standard Mohr techniques as chlorosity and converted to salinity.

Turbidity readings were made in a Klett colorimeter with a blue filter, calibrated with distilled water to which known amounts of suspensoids had been added.

Oxygen was determined by a modified Winkler method, full description of which can be found in the Texas A. & M. Research Foundation Report (1961).

Inorganic phosphate concentrations were determined colorimetrically following the ammonium molybdate-stannous chloride method.

Hydrological Results

The monthly averages of each of the physico-chemical parameters in the three sub-areas are given in Figs. 2–6. For more details on the hydrological results, see “Hydrological and Biological Studies of the Mississippi River—Gulf Outlet Project,” Texas A. & M. Research Foundation (1961).

TEMPERATURE

Monthly mean temperatures are given in Fig. 2. A minimum of 5.2°C was present at SBB, sub-area 2, in February 1960 and a maximum of 34.9°C was found at RB, sub-area 1, in July 1960. The seasonal pattern is also very similar for each sub-area. The greatest increase in temperature occurred between March and April 1960 and the greatest decrease between November and December, in both 1959 and 1960.

SALINITY

Monthly salinities are given in Fig. 3. The average monthly salinity of sub-area 1 was 2.88 ‰ compared with 13.9 ‰ in sub-area 3. Sub-area 2 had an intermediate value of

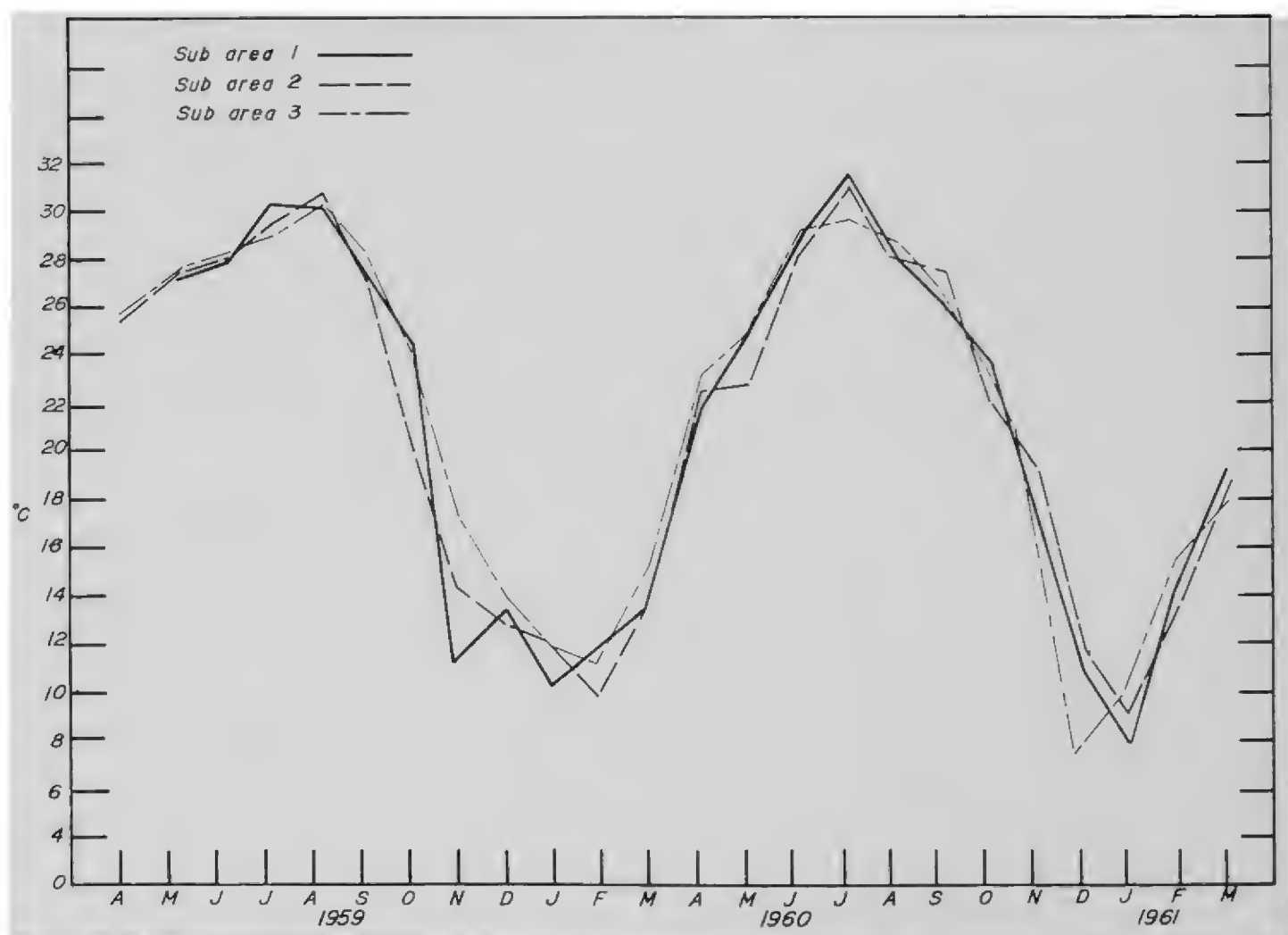


FIG. 2. Monthly average temperatures (°C) for each sub-area.

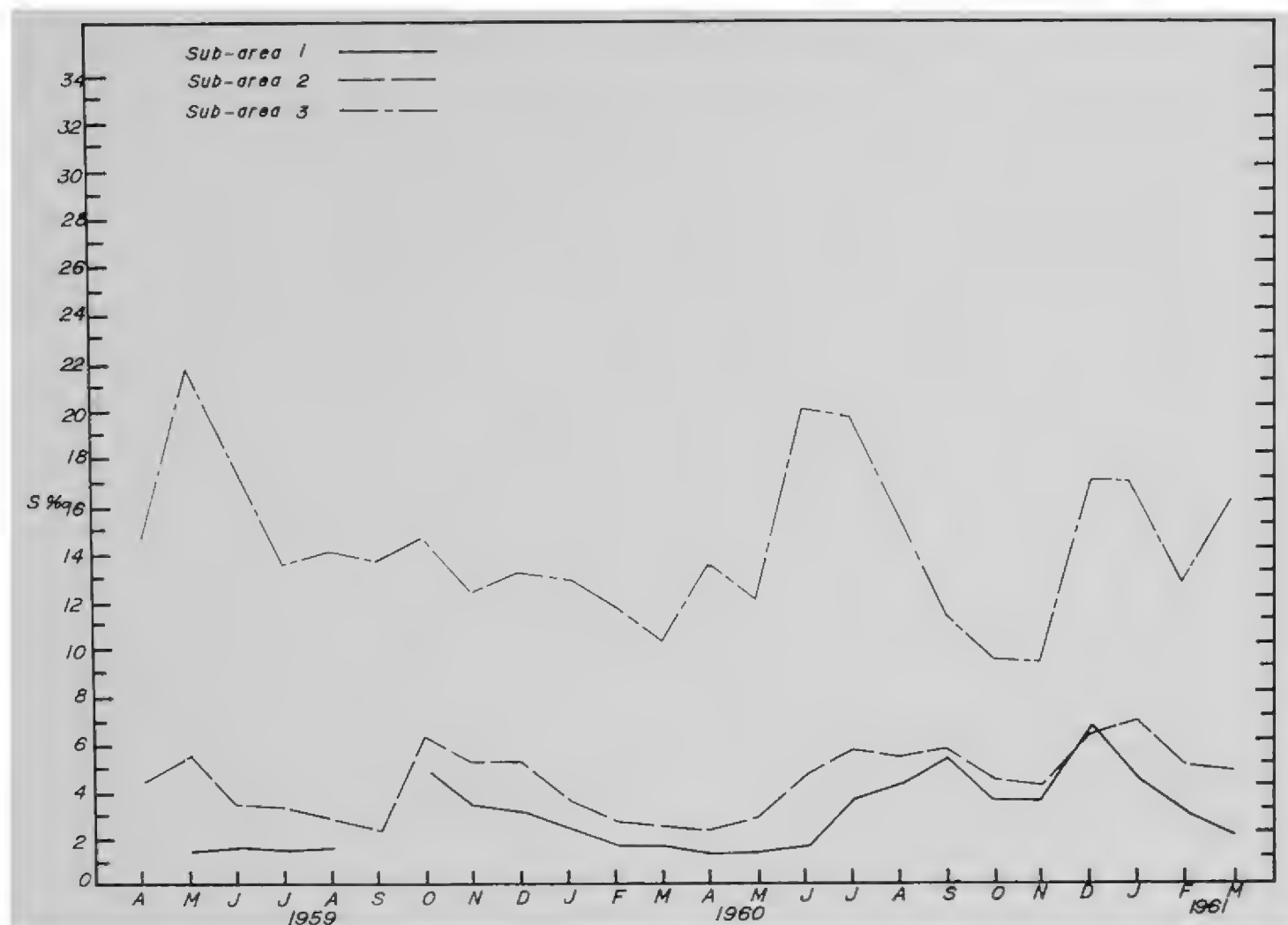


FIG. 3. Monthly average salinity (‰) for each sub-area.

4.18‰. The lowest salinity, 0.53‰, occurred in sub-area 1 at station BD in April 1960. The highest salinity, 25.43‰, was recorded in July 1960 at station LFF in sub-area 3. In sub-areas 2 and 3 salinities were at their minima in March and were consistently low in April and May. In sub-area 3 two notable salinity peaks were present, one during June-July 1960 and the other during December-January 1960-61. There were seasonal variations in salinity from one year to the next (Fig. 3).

TURBIDITY

Turbidity values are given in Fig. 4. The maximum turbidity, 0.77 g/L, was recorded at RB, sub-area 1, in February 1960. The minimum turbidity, 0.02 g/L, was recorded in several stations during the summer. High values were generally found from January through April, while the low values were recorded during the early summer and fall. Sub-area 1 had the greatest average turbidity and greatest seasonal variation of all the three sub-areas, followed by sub-areas 2 and 3. Variations of the turbidity in sub-area 3 seem independent of the variations in the other two sub-areas.

OXYGEN

Monthly dissolved oxygen averages are given in Fig. 5. A minimum oxygen value, 0.12 ml/L, was found at Station BD, sub-area 1, in September 1960. A maximum oxygen value, 7.41 ml/L, was found at Station BB, sub-area 2, in February 1961. Average monthly values were about 4.00 ml/L in all three sub-areas. During this investigation the highest oxygen values were found during the coldest months, that is, from December

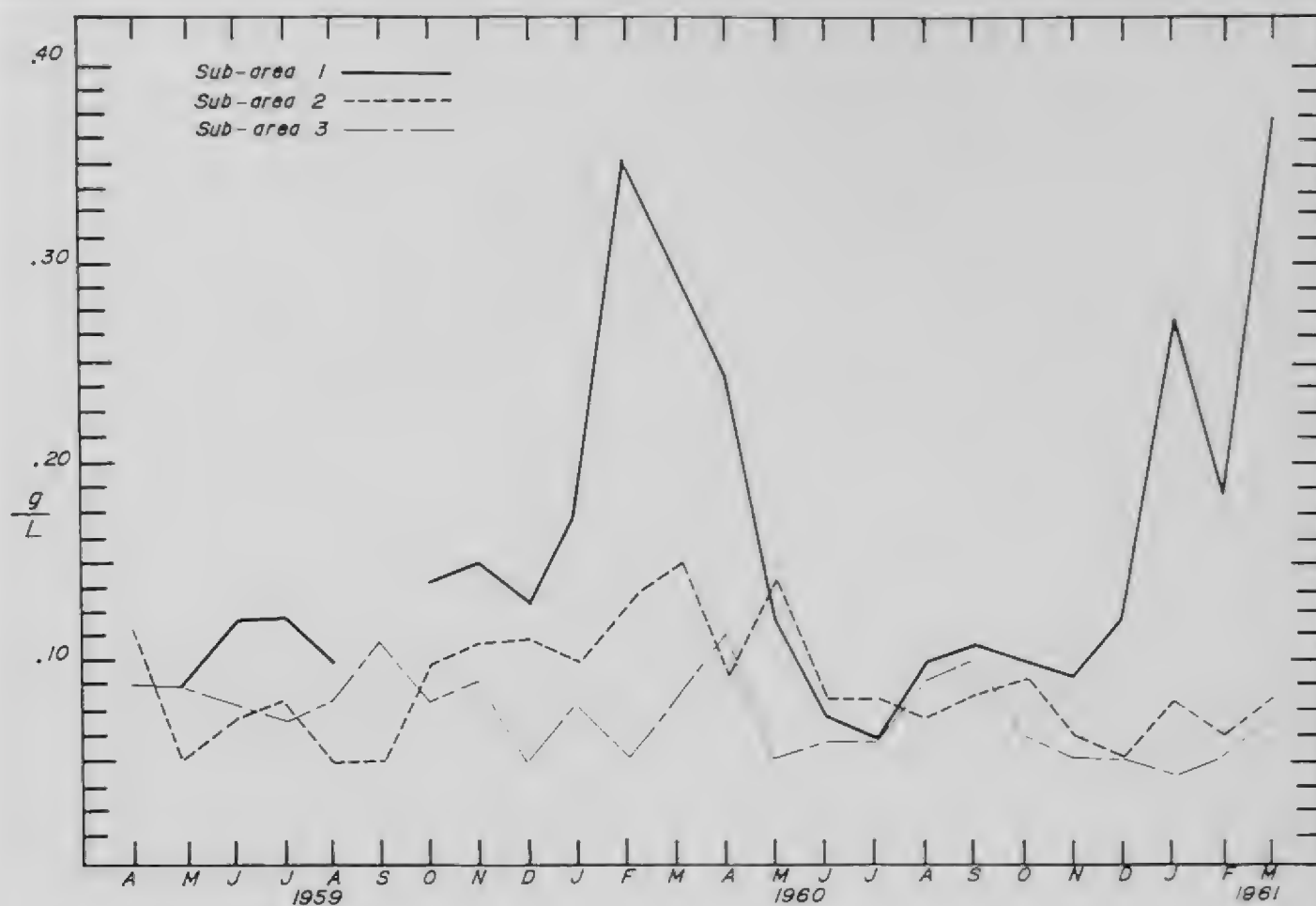


FIG. 4. Monthly average turbidity (g/L) for each sub-area.

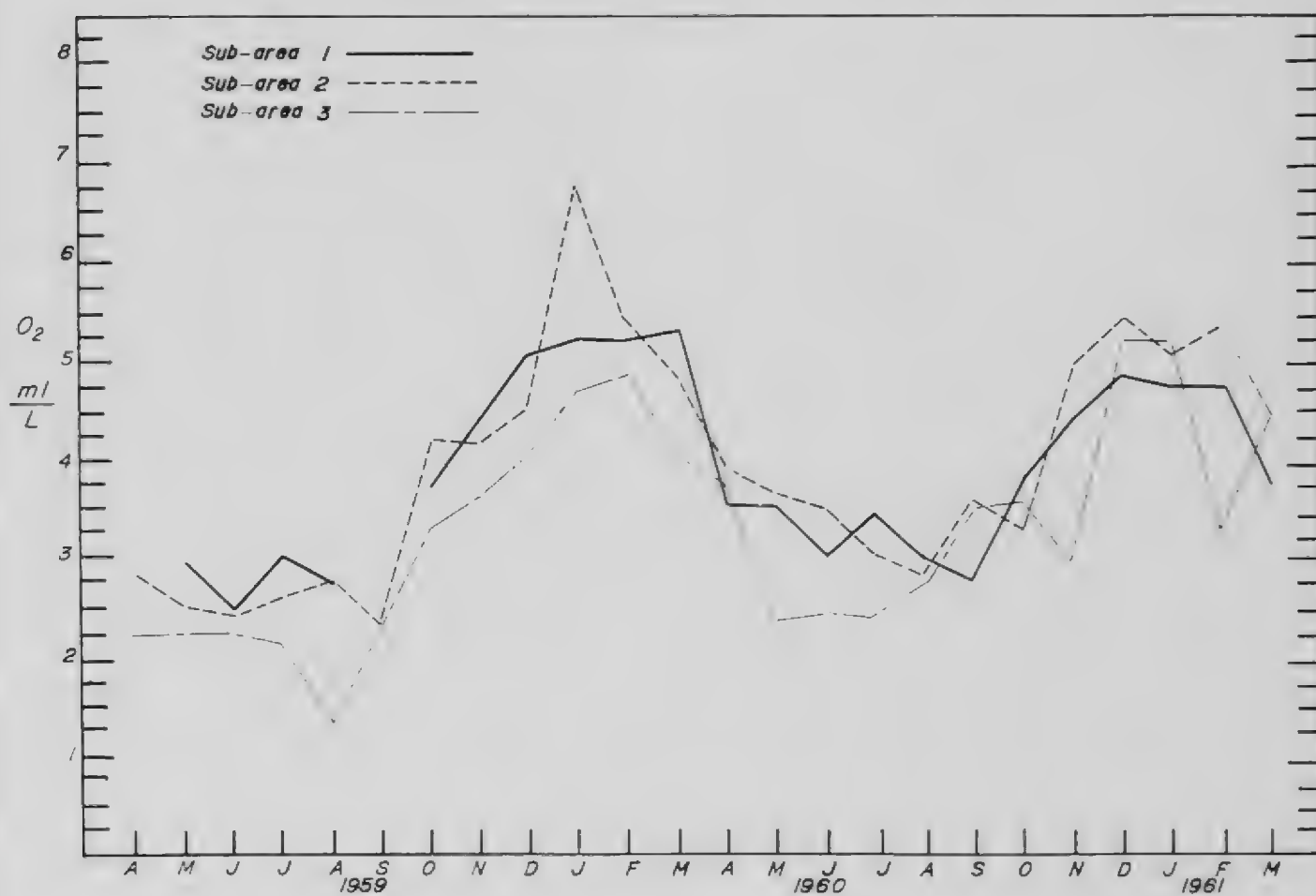


FIG. 5. Monthly average oxygen (ml/L) for each sub-area.

1959 to February 1960. The lowest values were encountered in the summer between June and August 1960 (see Fig. 5).

INORGANIC PHOSPHATE

Monthly inorganic phosphate concentrations are given in Fig. 6. The lowest phosphate value was $0.04 \mu\text{g-at./L}$ at station SBB, sub-area 2, in October 1960. The highest value, $8.24 \mu\text{g-at./L}$, was at station BD, sub-area 1, in March 1961. Average values decreased from $2.11 \mu\text{g-at./L}$ in sub-area 1 to $0.21 \mu\text{g-at./L}$ in sub-area 3. The seasonal range was greater in sub-area 1; the other two sub-areas showed only minor variations (Fig. 6).

Results of Zooplankton Studies

COMPOSITION OF THE ZOOPLANKTON

The zooplankton in the project area was mainly dominated by the following copepods: *Acartia tonsa*, *Eurytemora hirundoides*, and *Oithona* spp. Of these, *A. tonsa* was the most ubiquitous and most common. Others are listed in Table 1. Following is a list of taxa identified in the zooplankton collections: Foraminifera, medusae, *Mnemiopsis* sp., *Beroe* sp., *Tomopteris* sp., leeches, Acarina, *Acartia tonsa*, *Centropages hamatus*, *Eurytemora hirundoides*, *Labidocera aestiva*, *Paracalanus crassirostris*, *Pseudodiaptomus coronatus*, *Tortanus setacaudatus*, copepod nauplii, harpacticoids, *Eucyclops agilis*, *Cyclops panamensis*, *Cyclops vernalis*, *Macrocyclus albidus*, *Oithona* spp., *Ergasilus* sp., Cladocera, ostracods, *Argulus* sp., Cirripedia nauplii, Cirripedia cyprids, mysids, isopods, gammarids, shrimp larvae, zoeae, megalops, small crabs, snail veligers, cyphonaute larvae, echinoplutei, *Oikopleura dioica*, anchovy, croakers, gulf killifish, menhaden, silverside, striped mullet, worm eel, fish larvae and fish eggs.

The name *E. hirundoides* was retained in this investigation to facilitate the comparison with earlier studies. This copepod has been named *E. hirundoides* and *E. affinis*.

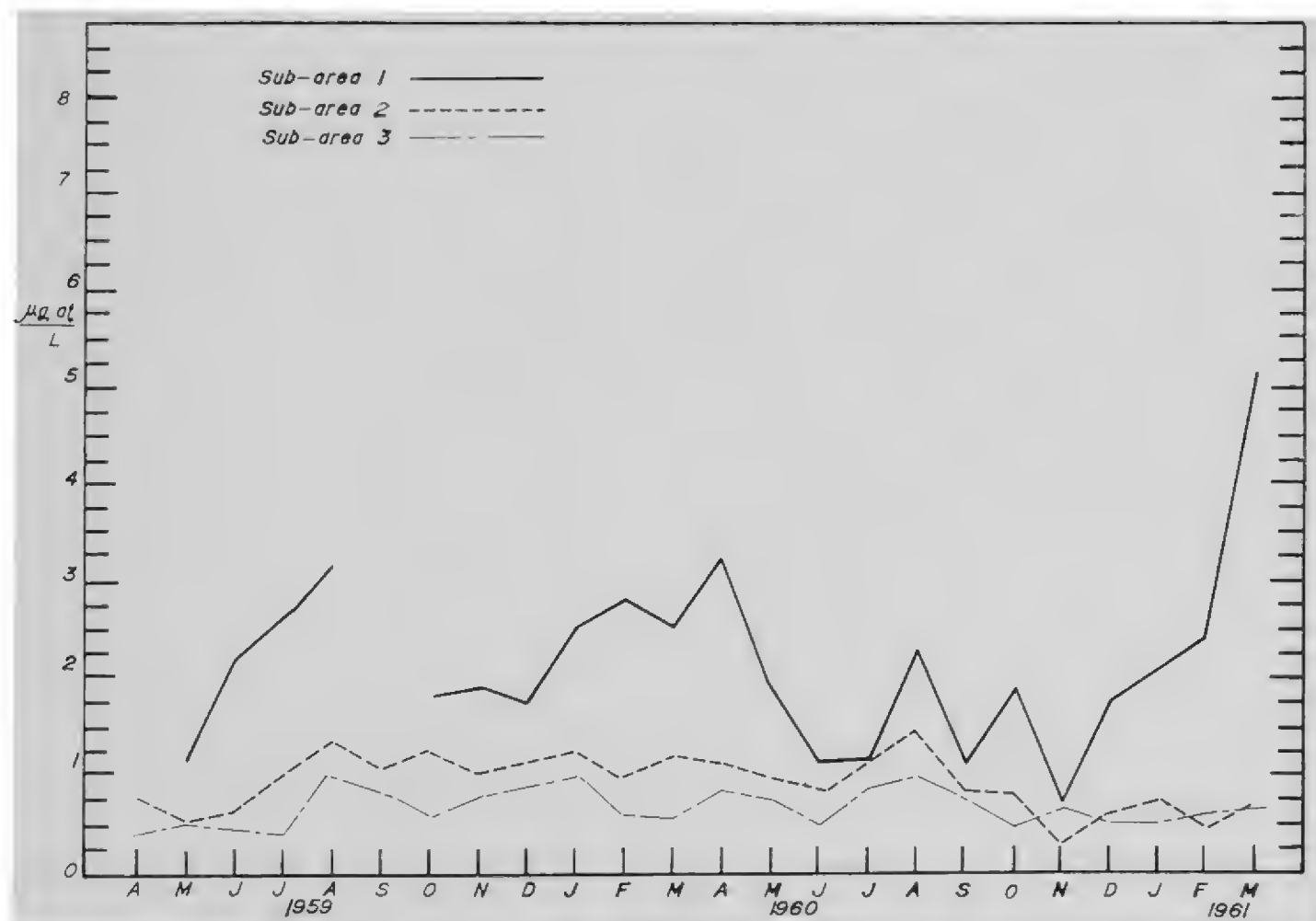


FIG. 6. Monthly average inorganic phosphate ($\mu\text{g-at./L}$) for each sub-area.

Wilson (1959) believes that "most American records" of *E. hirundoides* were in fact records of *E. affinis*.

Some of the morphological characteristics suggest one copepod to be *Oithona similis*. However, no positive species identification was obtained.

DISTRIBUTION OF THE ZOOPLANKTON

Certain characteristic associations were found in each of the three sub-areas. Sub-areas 1 and 2 were characterized by the presence of fresh or brackish water organisms, such as water mites (Acarina), parasitic forms (*Argulus* sp., *Ergasilus* sp.), or copepods (*Eurythemora hirundoides*). Sub-area 3 possessed representatives of the coastal marine waters, such as the copepods: *Centropages hamatus*, *Labidocera aestiva*, *Paracalanus crassirostris*, *Pseudodiaptomus coronatus*, *Tortanus setacaudatus* and *Oithona* sp., and other invertebrates such as medusae, ctenophora, echinoplutei, cyphonaute larvae, molluscan larvae, pelecypod larvae, and *Oikopleura dioica*.

The fauna common to all areas studied included: (a) holoplankton such as the copepod *Acartia tonsa* which can survive and live within extremes of salinity; (b) meroplankton such as crab zoeae, shrimp and fish larvae which migrate from the salt water to the more protected brackish areas where there is an abundant food supply.

The relative abundance of zooplankton for each station in the three sub-areas is given in Table 1. This table shows that sub-area 1 had the largest population followed by sub-areas 2 and 3 respectively. This was primarily caused by the preponderance of *Acartia tonsa* in sub-area 1.

Fig. 7 shows that *Acartia tonsa* not only was present everywhere at all times during this investigation, but was the principal component of the zooplankton: *Acartia* was nearly twenty-five times more abundant than *Eurythemora hirundoides*, the second copepod in numerical abundance. Table 1 shows that sub-area 1 had the largest numbers of plankton organisms followed closely by sub-area 2, while sub-area 3 had only a little more than half the population of sub-area 1 or 2. There is a general decrease in number of *A. tonsa* from Lake Borgne stations to the stations within the bayous, that is from LB and BDL in sub-area 1 and SBB and BML in sub-area 2. In sub-area 3, except for station LAS where the plankton catches were invariably inferior to those of other stations, there was less than a 10 per cent difference among the catches of the four remaining stations.

Eurythemora hirundoides occurred in great abundance in sub-area 1, especially in Lake Borgne stations. In sub-area 2 the *Eurythemora* population was only one-fourth of that in sub-area 1. *E. hirundoides* was never recorded from sub-area 3. On the other hand *Oithona* sp. was found more frequently and in greater abundance in sub-area 3 than in the other two sub-areas. The latter sub-areas had approximately the same size population.

Copepod nauplii were found in greatest numbers in sub-areas 1 and 2. Their population density in sub-area 3 was only one-third of that of the nauplii of sub-area 2.

Cirripedia nauplii in sub-area 1 were found in numbers almost equal to those in sub-area 2. On the other hand, sub-area 3 had nearly ten times as many as either one of the other areas.

Crab zoeae were more abundant in sub-area 3 but the differences among the three sub-areas were small.

TABLE 1
Catch per 5-minute haul of representative plankters in all three sub-areas*

	Sub-Area 1					Total	Sub-Area 2					Total	Sub-Area 3					Total
	BD	BDB	RE	BDL	LE		SBB	BML	JDY	BG	BM		BPPN	LAN	LAS	LMN	LFF	
Total samples per station:	41	34	39	42	28	Total	19	40	40	41	41	Total	35	35	31	35	26	Total
Organisms:																		
<i>Acartia tonsa</i>	163	103	94	209	412	981	465	274	60	50	38	887	111	109	64	93	92	469
<i>Eurytemora hirundoides</i>	5	6	11	15	48	85	9	7	1	2	2	21	....	....	....	....	....	....
<i>Paracalamus crassirostris</i>	....	....	....	....	....	....	....	....	....	....	....	....	x†	....	x	3	7	10
<i>Pseudodiaptomus coronatus</i>	....	....	....	....	....	....	....	....	....	....	....	....	1	x	1	1	24	27
Harpacticoids	1	x	1	x	....	2	x	x	x	x	x	x	x	x	x	x	x	x
Cyclopoids	9	2	15	7	1	34	x	x	x	x	x	x	x	x	x	x	x	x
<i>Ergasilus</i> sp.	x	x	x	x	x	x	x	x	x	x	x	x	x	x	....	....	....	x
<i>Oithona</i> spp.	1	x	x	x	1	2	x	x	x	x	x	x	8	6	15	12	40	81
Copepod nauplii	21	4	12	8	28	73	18	9	6	9	6	48	1	5	11	2	16	35
Cirripedia nauplii	1	2	1	1	2	7	2	1	1	1	1	6	11	3	6	6	9	35
Zoeae	1	2	3	1	x	7	1	2	1	1	1	6	4	1	1	2	2	10
Fish larvae‡	123	42	21	171	155	512	71	21	15	9	3	119	6	10	24	12	9	61

* All figures represent the mean in thousands per station.

† x indicates that the mean number was less than 1000. Dashes indicate that no specimens were found in the aliquots examined at that particular station.

‡ Figures given for the fish larvae represent the total numbers per station.

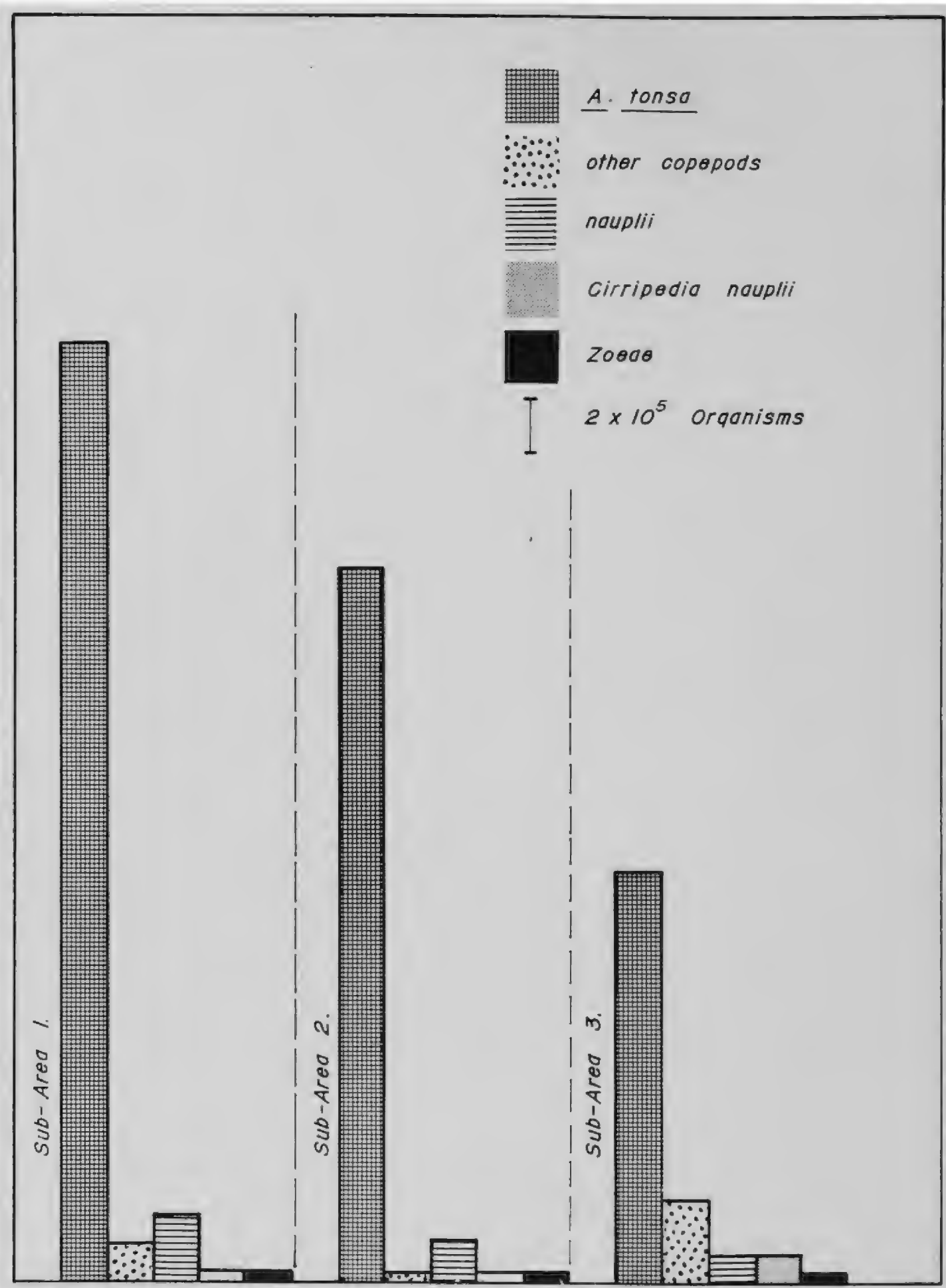


FIG. 7. Total numbers of the main plankters in all three sub-areas.

SEASONAL DISTRIBUTION OF THE ZOOPLANKTON

Seasonal patterns of distribution are given in Figures 8-14 showing that all three sub-areas exhibited marked seasonal changes in the species composition as well as in the number of zooplankton organisms per volume. All numbers are given as monthly aver-

ages. Thus, when 3 hauls were made at one station during one month the three results were added up then divided by 3, etc. A well-defined population explosion was observed in April 1960 which coincided with the tremendous increase of *Acartia tonsa* during that month (see Fig. 8). Minor peaks were also noticed in the early fall of 1960. The peaks in 1959 were much smaller than in 1960 and occurred during October in sub-area 2, during November in sub-area 3, and during December in sub-area 1.

Eurytemora hirundoides was caught between November and July with a seasonal maximum in April in sub-areas 1 and 2 (see Fig. 9). The seasonal maximum of *Oithona* spp. also occurred in April in sub-area 3, but a secondary peak in the fall of 1959 was

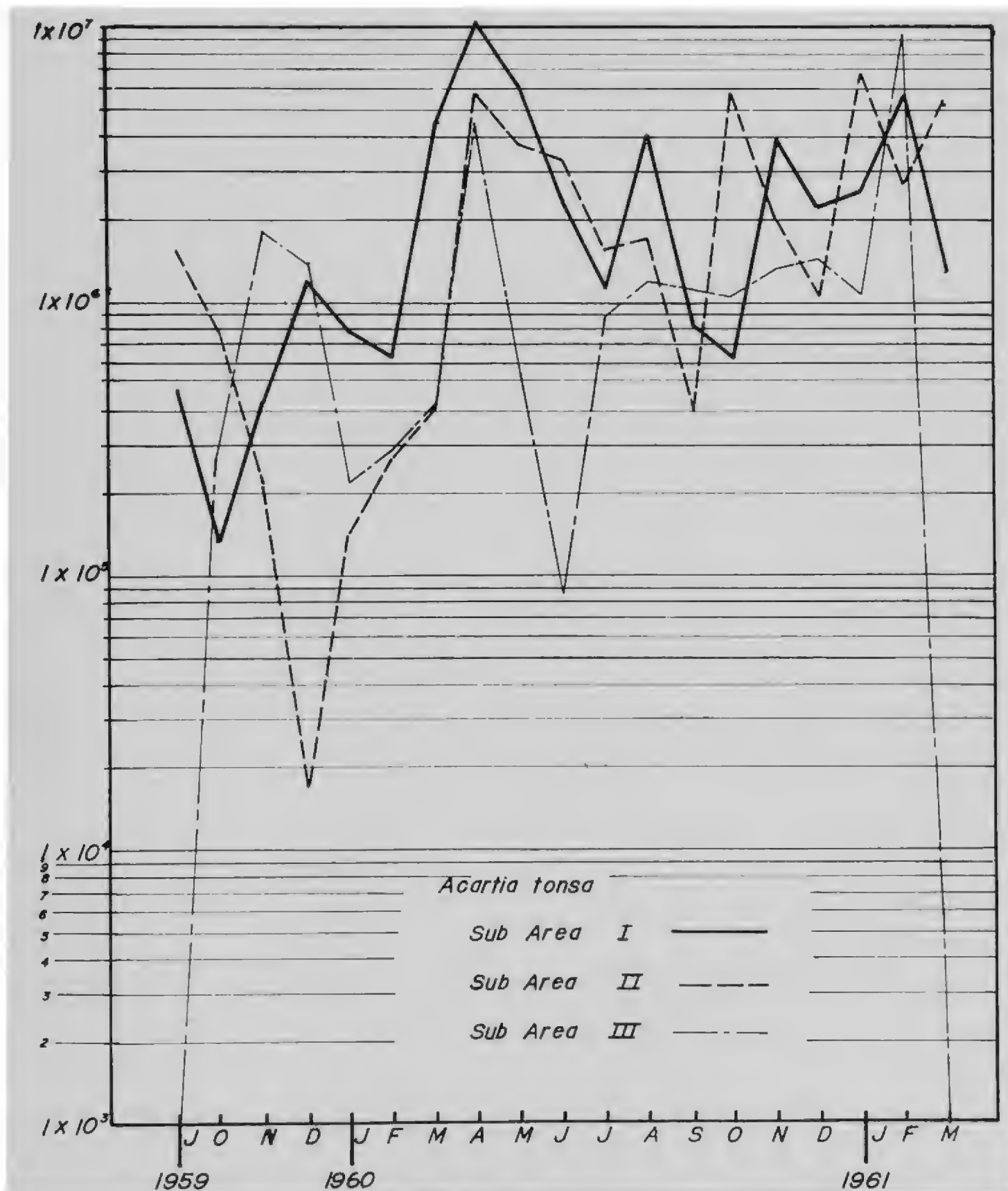


FIG. 8. Monthly distribution of *Acartia tonsa* in sub-areas 1, 2, and 3.

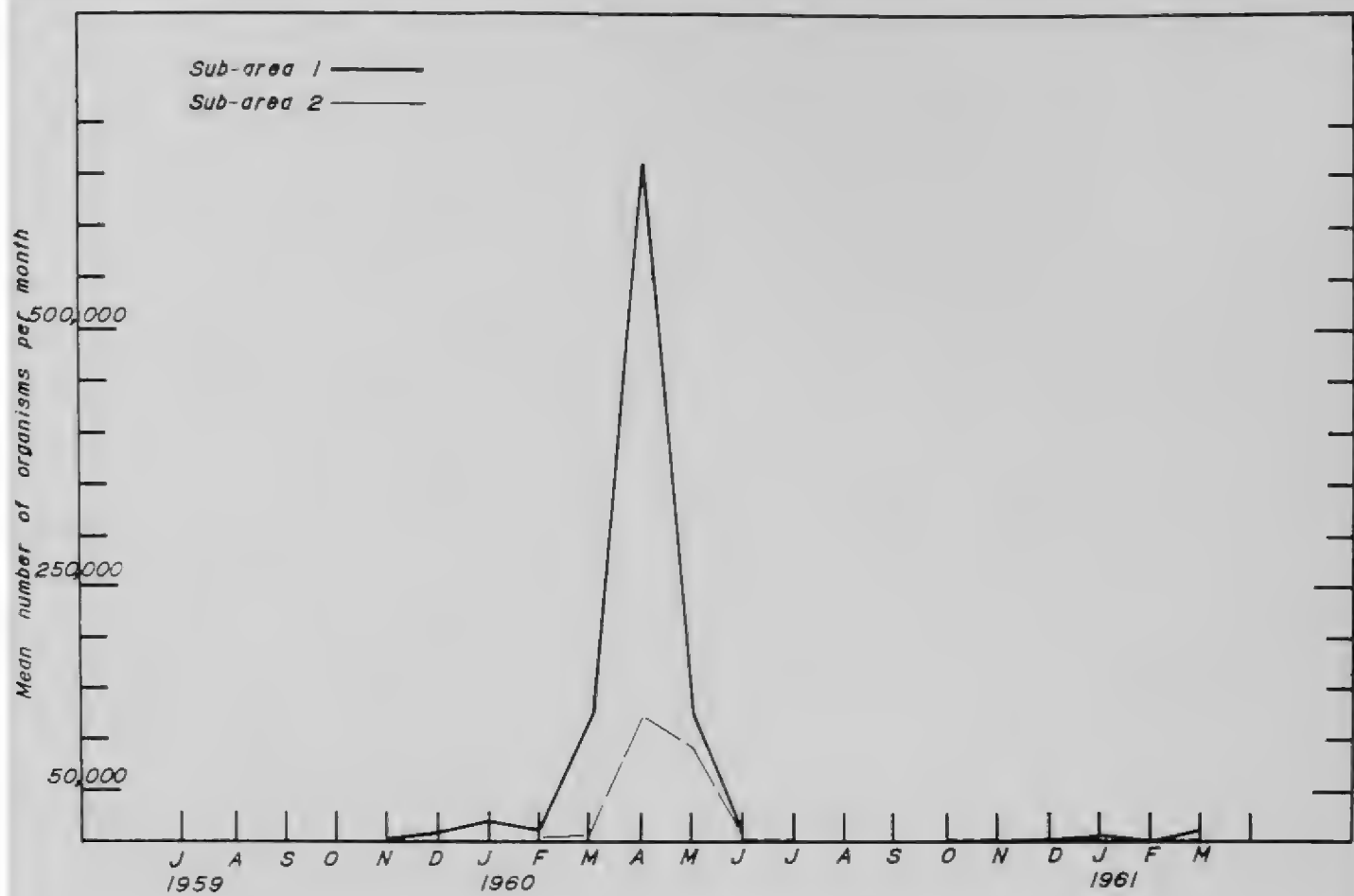
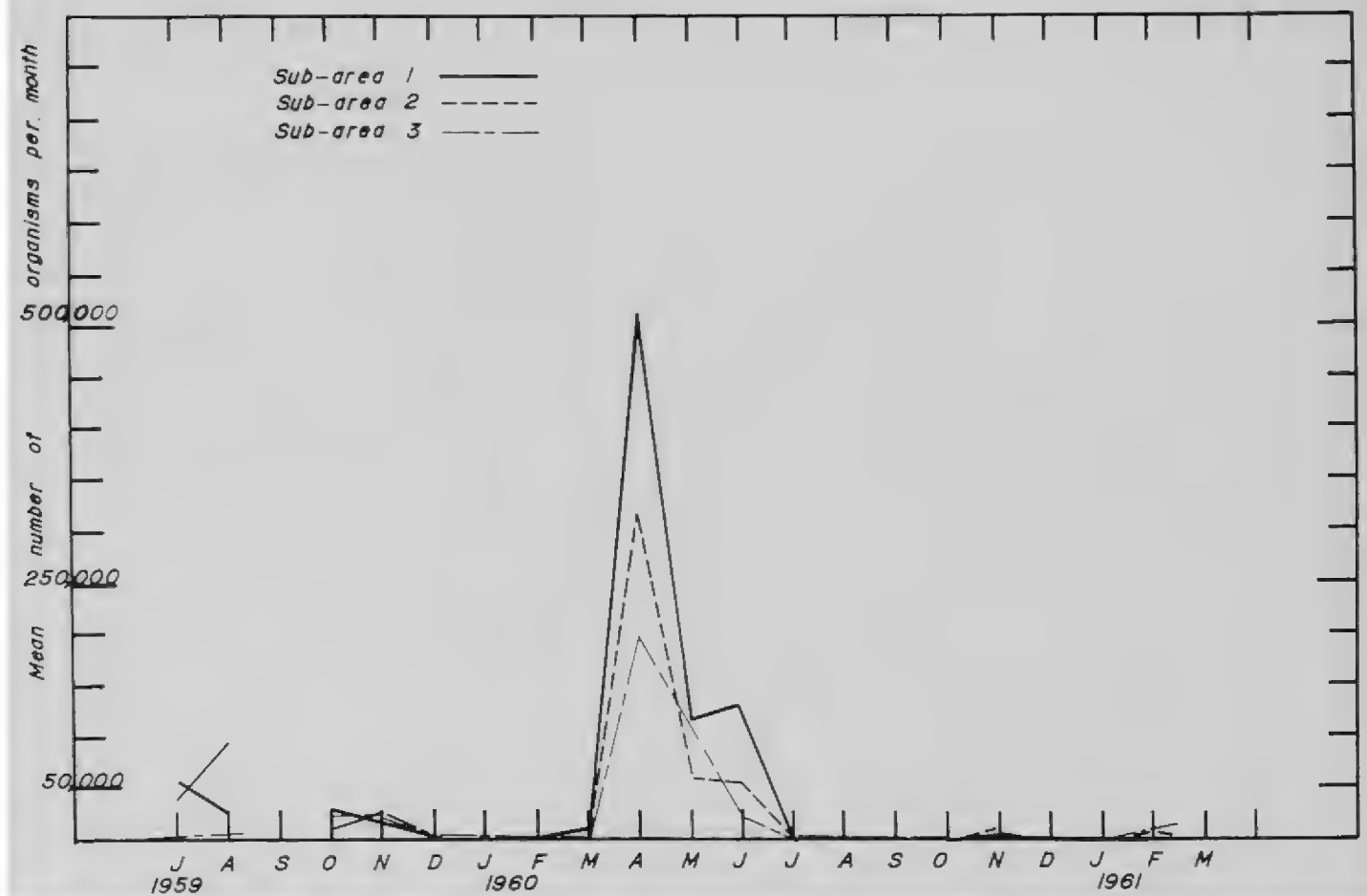
FIG. 9. Monthly distribution of *Eurytemora hirundoides* in sub-areas 1 and 2.

FIG. 10. Monthly distribution of the copepod nauplii in sub-areas 1, 2, and 3.

not repeated in 1960. *Oithona* spp. was present between April and December, but disappeared during the colder months until the next cycle.

Copepod nauplii were present at all times during the year with their highest numbers occurring in April 1960 (see Fig. 10). In 1959 there was an increase in number in the fall, to which there was no counterpart in 1960.

Figures 11 and 12 show that the Cirripedia nauplii and cyprids had spring maxima in sub-areas 1 and 2 from May to June 1960 with minor peaks in August. On the other hand, in sub-area 3 the spring maxima occurred in April. The distribution of the cyprids was related closely to that of the nauplii although their numerical increase in April was small, as shown in Fig. 12.

Data on the distribution of zoeae in 1959 are incomplete (Fig. 13). Possibly there was a seasonal peak ending in July in sub-areas 1 and 2. Not enough information was available from sub-area 3 to infer any trend. The following year, sub-area 1 had two peaks, one in April and the other in September. In sub-area 2 the April maximum was followed by another maximum in August. In sub-area 3 the greatest numbers were found in September with two other periods of abundance, in May and July. No zoeae were caught after October, either in 1959 or 1960 (see Fig. 13). Only a few megalops were present in the samples; all were taken in July.

Fish larvae were present the first six months of the year, but after June they were caught only occasionally.

Ergasilus sp. had its main period of abundance in late spring or early summer.

The Cladocera were scattered throughout the whole year without any well-defined seasonal maximum.

No seasonal variation was evidenced in the distribution of the ostracods.

Gammarid amphipods were slightly more numerous during the colder months.

Mysids were not present in the catches between March and August.

The water mites (order Acarina) were collected intermittently throughout the survey.

Leeches were found only on two occasions in December and February.

Centropages hamatus appeared only in December 1960.

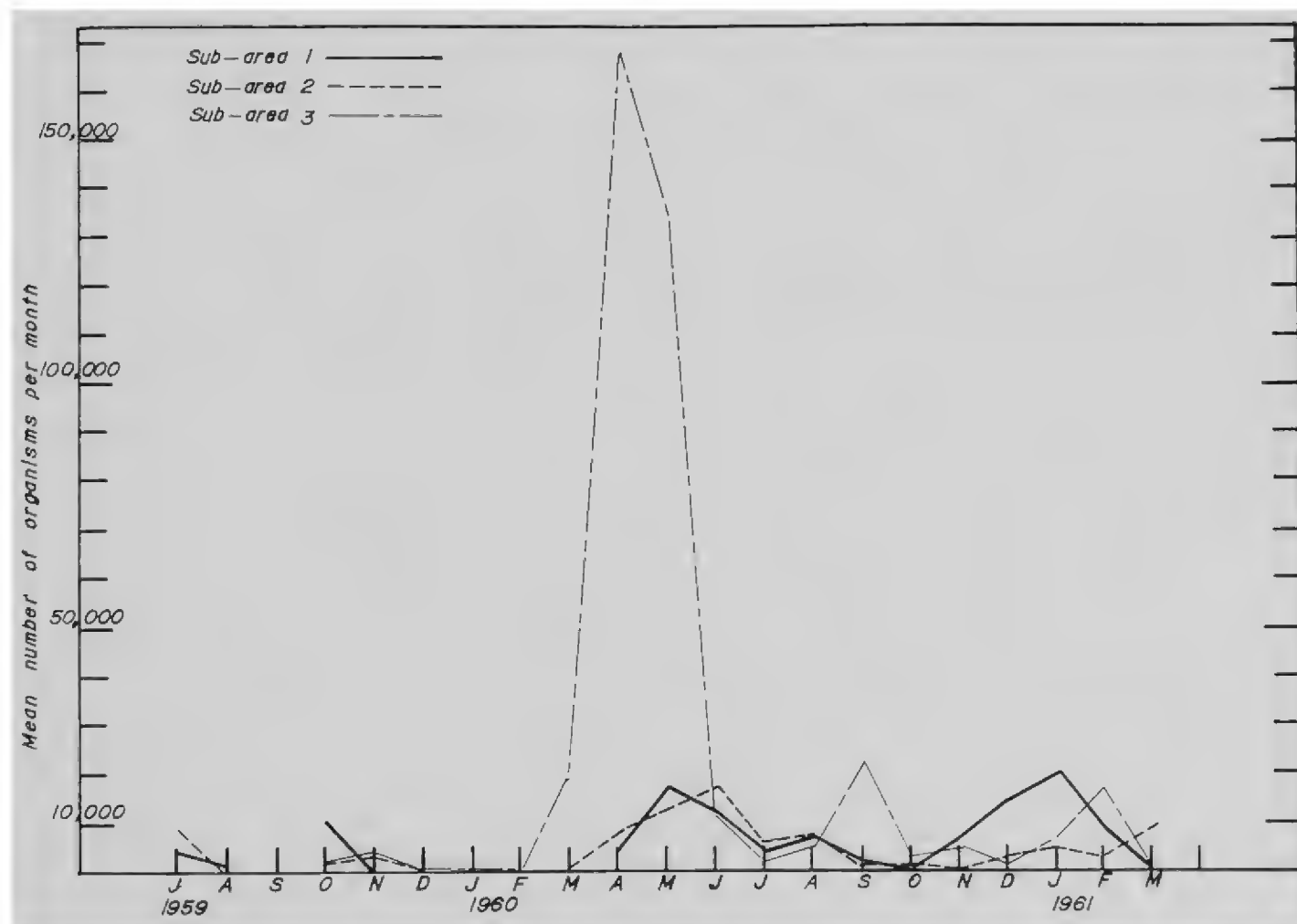


FIG. 11. Monthly distribution of the Cirripedia nauplii in sub-areas 1, 2, and 3.

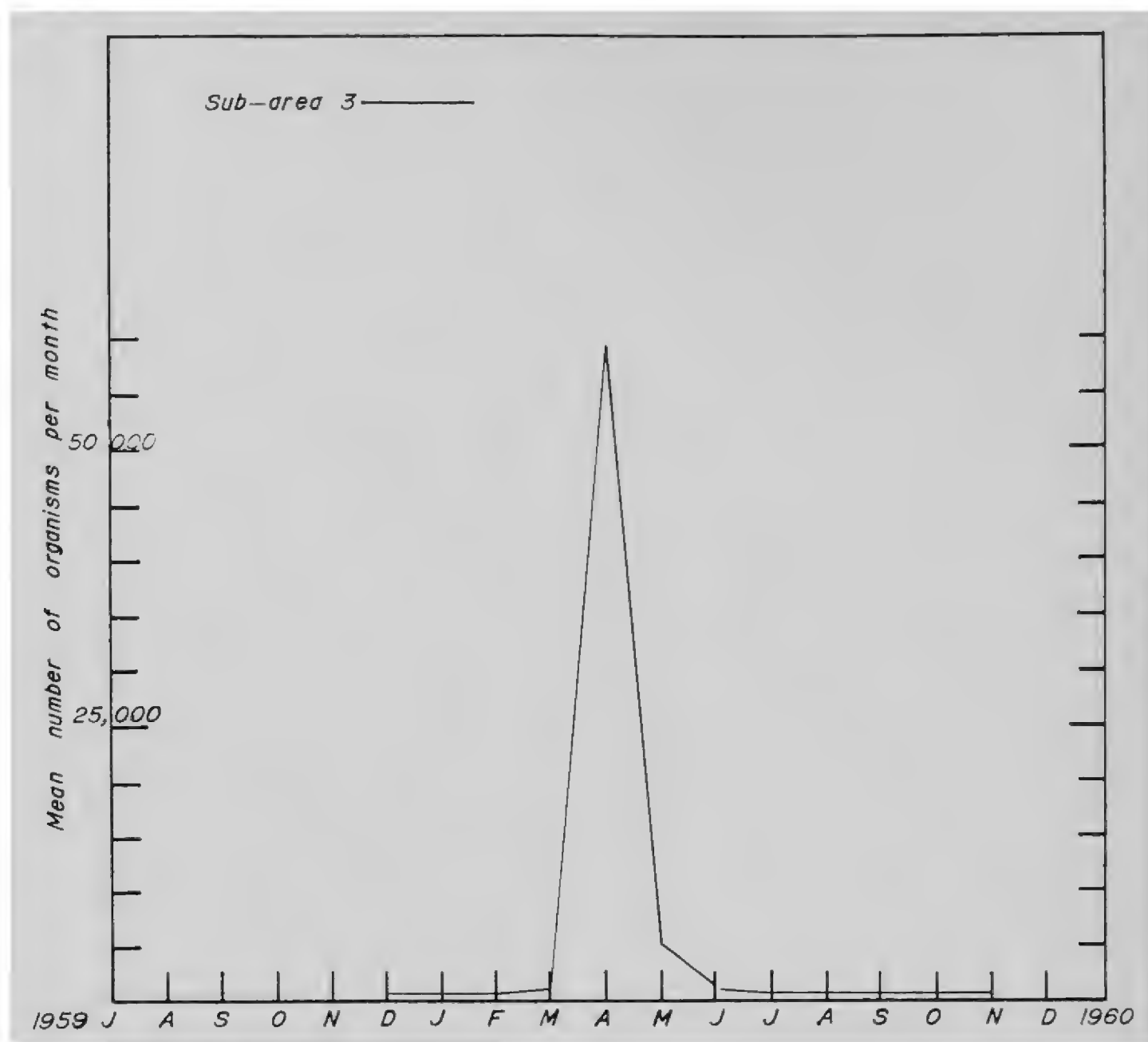


FIG. 12. Monthly distribution of the Cirripedia cyprids in sub-area 3.

Labidocera aestiva was found once in April 1960 and was present in September and October 1960.

Paracalanus crassirostris appeared in April and May.

Pseudodiaptomus coronatus had spring and fall maxima with reduced numbers in between.

Tortanus setacaudatus was present in the summer and fall of 1959 and 1960. It was sparsely distributed throughout the rest of the year.

The ctenophore, *Mnemiopsis* sp., was more abundant than *Beroe* sp. The latter was present mainly in the summer while the former was found frequently in winter and spring but was scarce or absent in the warmer months.

Medusae were recorded in winter and spring.

Echinoplutei were present during the summer and early fall months with a distinct peak in August.

Cyphonaute larvae were present in the fall of 1959 and in the spring of 1960.

The pelecypod larvae, although too small to be retained effectively by the net, were found in large numbers in April at LFF, sub-area 3. Almost all the specimens were collected in spring or early summer.

Oikopleura dioica had a small peak in April and was present through October.

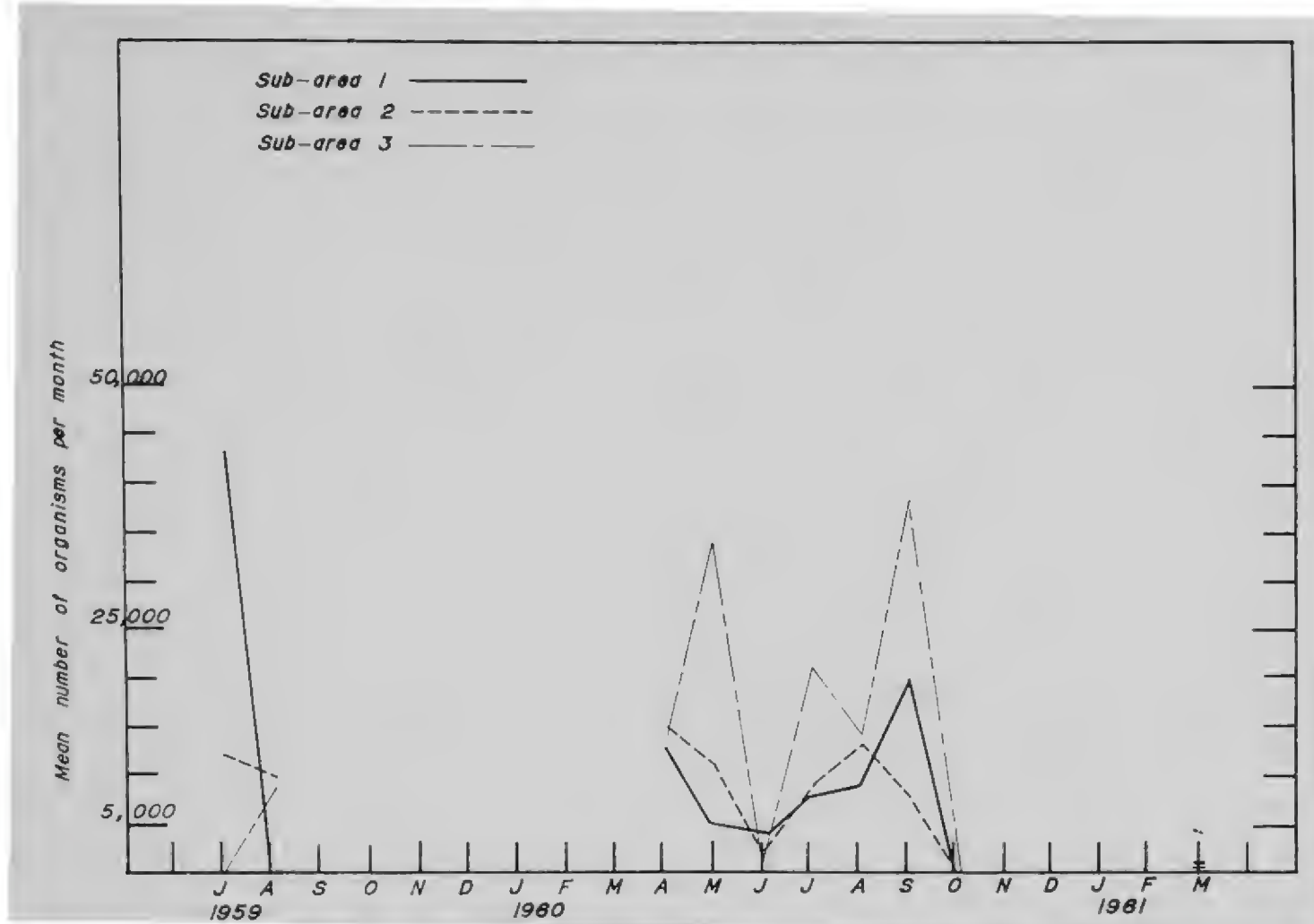
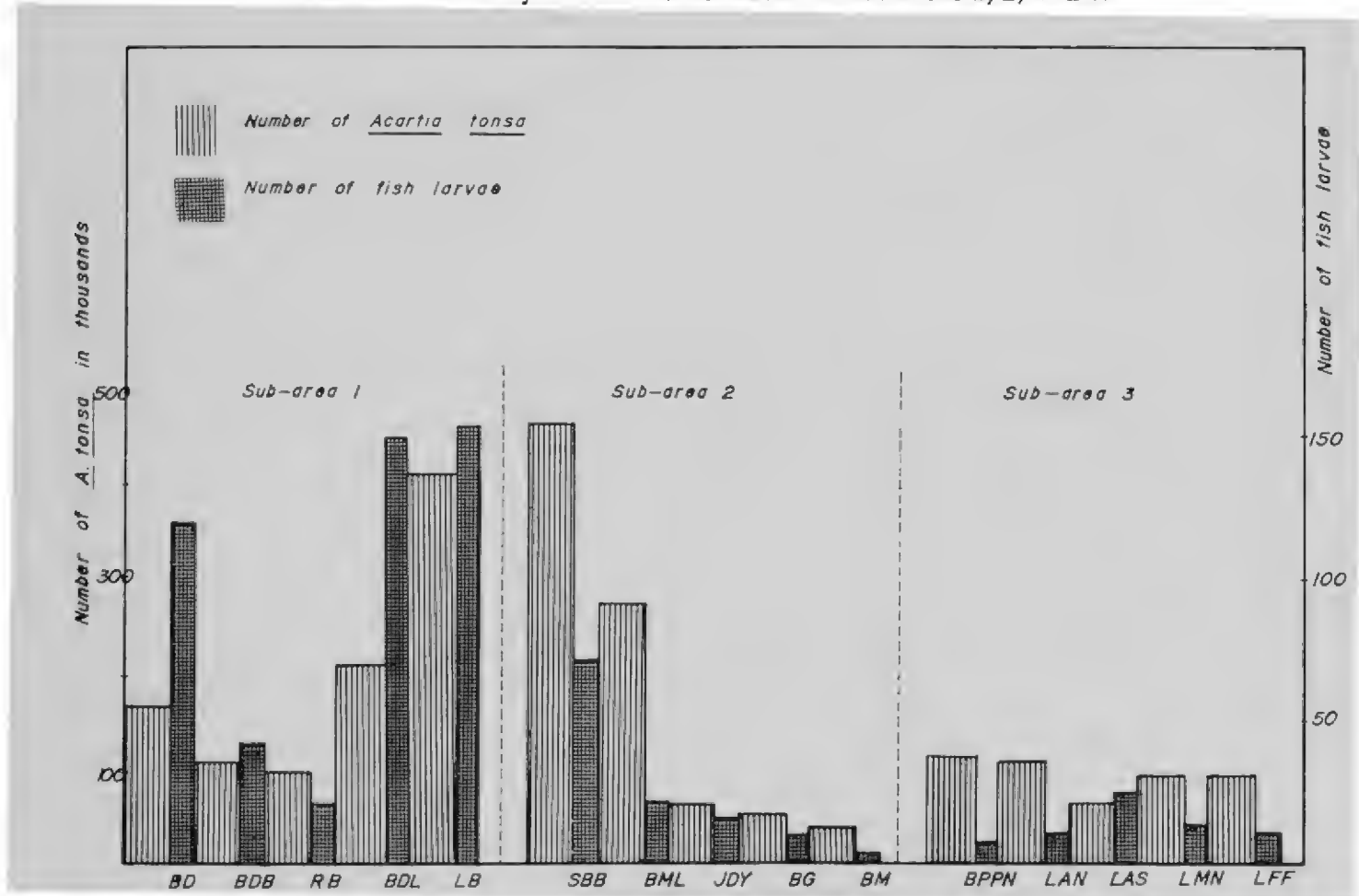


FIG. 13. Monthly distribution of zoetae in sub-areas 1, 2, and 3.

FIG. 14. Abundance of fish larvae and *Acartia tonsa* in the project area.

Harpacticoids followed the trend of the majority of the plankters by having their yearly peak in April. Similarly, the cyclopoids were significant only in April and May although they never represented more than a small fraction of the copepods.

The polychaete larvae reached a peak in April-May and in October-November of 1959 and 1960.

The isopods were present occasionally throughout the survey in all three sub-areas, mainly in the bayous.

The shrimp larvae were caught more often in April, but were absent from November to March.

Discussion of Hydrological Conditions

TEMPERATURE

On the average there was very little temperature difference among the three sub-areas. Even during the coldest months, December, January, and February, or when the temperatures were at their highest in July and August, *A. tonsa* was present in large numbers (Fig. 8). However, *E. hirundoides* was absent from the hauls during the summer months.

Although the temperature differences from one year to the next were only minor, there was a significant difference in the size of the plankton population during the two years.

SALINITY

The planktonic fauna reflected the salinity conditions in the project area. Some of the plankters were of either marine or fresh water origin. The majority, however, were typical of brackish conditions. Numerically the marine and fresh water forms were of little importance; both were transient.

Lake Pontchartrain, connected to the project area by a narrow passage, the Rigolets, also is submitted to the same influences. Darnell (1962) noted that during periods of high salinity a large element of typically marine forms entered the lake. During periods of low salinities, fresh water species appeared in some numbers. The rest of the time a graded species spectrum was present.

Some of the Cladocera, Ostracoda or cyclopoid copepods which were found in greatest concentration at station BD—the lowest salinity station of sub-area 1—were encountered also occasionally at the adjacent stations in sub-area 1 and sometimes in sub-area 2. On the other hand, medusae and ctenophores were rarely found outside sub-area 3. Whereas in the fall of 1959 the collections showed the presence of typically marine forms in sub-area 3, this phenomenon was absent in 1960.

The variation in salinity may be the result of several factors, including winds driving Gulf water in and out of the marshes, and fresh water discharge from the Pearl River. An increase in salinity sometimes brought typically marine organisms into the project area, especially in sub-area 3, including *Oithona* sp., *P. crassirostris*, *P. coronatus*, *T. seticaudatus* and medusae.

The discharge of fresh water into the project area may have dispersed part of the autochthonous plankton population outside the sampling area possibly through Bayou Ycloskey, Bayou La Loutre and Bakers Canal, all of which were located outside the biological sampling zone. It is less likely that the currents carried the fauna through Bayou St. Malo, since there was little water exchange between Lake Borne and this bayou system (Texas A. & M. Research Foundation, 1961).

TURBIDITY

High turbidity values and high phosphates were found concomitantly in sub-areas 1 and 2. In both cases there was a decrease in values as salinity increased. Stations of sub-area 2 exhibited very little variation among themselves. Sub-area 3 had lower turbidity values than either of the other sub-areas suggesting the influence of the salt water in reducing turbidity values through flocculation and precipitation. No correlation was found between the number of copepods and the turbidity value. It is not impossible, however, that some copepods utilized the suspensoids as a food source (Darnell, 1961). Early fish stages may also find a food source in this suspended detrital material. Darnell (1958) considered the post-larval stages of fish as general scavengers. The greatest number of juvenile fish were encountered in sub-area 1. A similar explanation may account for the zoeae which were also more abundant in the same sub-area.

OXYGEN

All the averages of oxygen showed high values, more than 50 per cent saturation.

INORGANIC PHOSPHATE

The higher inorganic phosphate found in the bayous of sub-area 1 may be attributed to sewage contamination in the upper reaches of Bayou Bienvenue. Higher nutrient levels in this area may also be indicated by the population levels there.

Discussion of Populations

Acartia tonsa

Conover (1956) suggested that *A. tonsa* might attain an important position in the plankton community only when salinity restricted the presence of other copepods. Davis (1944) reported *A. tonsa* as the dominant copepod of Chesapeake Bay. Later Davis (1950) mentioned again *A. tonsa* as the most abundant of the copepods sampled in the brackish waters of southern Florida. Conover (1956) found *A. tonsa* in conjunction with *A. clausi* in Long Island Sound. *A. tonsa* was dominant only in the summer with a peak in August. In the Laguna Madre, *A. tonsa* was the major copepod, found in salinities ranging from 8 to 75 ‰, and was most abundant between 47 and 75 ‰ (Simmons, 1957). Similar findings were reported by Breuer (1957) in Baffin and Alazan bays where *A. tonsa* dominated the zooplankton populations also and accounted for large plankton volumes. The salinities in these two bays varied from 1 to 75 ‰. Fleminger (1956) in his survey of the calanoid copepods of the Gulf of Mexico found *A. tonsa* almost exclusively in those regions "where considerable amounts of land drainage water flow." Additional evidence shows that they are more successful in low salinities and land-locked bodies of waters than in competition with other copepods in the open ocean. Deevey (1948) recorded *A. tonsa* as the main species in the summer in Tisbury Great Pond. Deevey (1952 a, b) again described the important role of *A. tonsa* during the summer in Block Island Sound both from 1943 to 1946 and in 1949. In the surface waters of the Delaware Bay region, Deevey mentioned *A. tonsa* as the most important year-round

copepod species of the bay. At Great Pond, Falmouth, Massachusetts, Barlow (1952) found a greater concentration of *A. tonsa* in the Pond than in the outside waters of Vineyard Sound. In Alligator Harbor, *A. tonsa* was the second most numerous copepod throughout the year (Grice, 1956). In the Chicken Key area, *A. tonsa* constituted 60 per cent of population (Woodmansee, 1958). Off the Mississippi River mouth, Gonzalez (1958) recorded a spring maximum and conspicuous concentrations of *A. tonsa* in the winter. The environment itself does not seem to be a limiting factor in the proliferation of *A. tonsa*, but when the environment becomes less forbidding to other species, the competitors outgrow *A. tonsa*. Deevey (1948) noted that the disappearance of *A. tonsa* coincided with the arrival of large populations of *A. clausi* and *E. hirundoides*. Coker and Gonzalez (1960) found large numbers of *A. tonsa* only where species diversity was minimal and in the vicinity of Bahia Fosforente in Puerto Rico; few were found otherwise.

In Lake Ponchartrain, Darnell (1961) found the greatest abundance of copepods (of which *A. tonsa* was the major representative), at the surface in areas "characterized by mixing of water masses, bottom roiling, and proximity to eroding marshes." This description may be used to summarize the findings of this survey also.

Eurytemora hirundoides

E. hirundoides is a brackish water copepod with a preference for the less saline parts of its environment. Foster (1904) had recorded the species from the fresh and brackish waters of New Orleans and Calcasieu Pass in the Mississippi delta. Wilson (1932 a) mentioned *E. hirundoides* as one of the inner bay species in Chesapeake Bay. In Tisbury Great Pond it was present from November until July with a peak in March (Deevey, 1948); in Delaware Bay it was present only from March until May (Deevey, 1960). All these results are comparable to the findings of this investigation. Between July and November *E. hirundoides* did not occur in the plankton samples. The numbers in the Lake Borgne stations of sub-areas 1 and 2 were greater than in the bayou stations of these same sub-areas demonstrating the great similarity of distribution of *A. tonsa* and *E. hirundoides* with respect to the land masses. Deevey (1960) indicated that *E. hirundoides* was eurythermal and euryhaline and occurred in waters ranging from 0 to 24°C and salinities of 1 to 31 ‰.

COPEPOD NAUPLII

Stations SBB and LB, sub-area 1, had the largest copepod populations during this investigation and also had the largest nauplii populations. In sub-area 3 the number of nauplii increased in a seaward direction suggesting the marine origin of the adults. Since the #6 net does not sample these early copepod stages adequately, a considerable source of error was introduced thereby. Even the sixth and last stage of the *A. tonsa* nauplii was smaller than 0.239 mm (Conover, 1956). This biased sampling applied to forms smaller than 0.239 mm in their smallest dimension. If the net were 100 per cent efficient, theoretically they would not be caught at all.

During this investigation a certain ratio was maintained in all three sub-areas between the total number of copepods and copepodites and the total number of nauplii. The ratios were 2.75:1, 3.02:1, and 2.88:1, for sub-areas 1, 2 and 3 respectively. In other words, there was a direct relationship between the number of nauplii and the number of

adults or near adults. This distribution did not hold on a month-to-month basis, however. Peak numbers of copepods and copepodites were not followed by a comparable increase in the number of nauplii.

NAUPLII AND CYPRIDS OF BARNACLES

Although the distribution of the adults was undefined, it is reasonable to assume that the cirripeds are more numerous in sub-area 3 since both nauplii and cyprids were found in that sub-area in greater numbers.

ZOEAE

Observations on the distribution of the crab zoeae tend to support some of the hypotheses advanced by Darnell (1959). Darnell had noted that in spite of the frequent appearances of benthic forms in the surface plankton of Lake Pontchartrain, few crab larvae were present. He then concluded that *Callinectes sapidus* spawned nearby in Lake Borgne or in Chandeleur Sound. Ovigerous females were absent from Lake Pontchartrain in February or March and again in August and September. Although the counting procedures did not prove that zoeae caught in the project area were exclusively blue crab zoeae, it is very likely that the abundance of the adult blue crabs (Texas A & M Research Foundation, 1961) is reflected in the abundance of the larval stages in the samples. In sub-areas 1 and 2 which are closely related to Lake Pontchartrain through the Rigolets and Chef Menteur the crab zoeae were found in greater abundance both in April and in August–September.

FISH LARVAE

The fish larvae and post-larvae remained largely unidentified. It is believed, however, that the majority belonged to the genus *Anchoa* sp. Sub-area 1, which had the greatest number of copepods, also had the greatest number of fish larvae. In sub-area 2 the number of fish larvae had dwindled to one-fourth that of sub-area 1 and in sub-area 3 it was only one-eighth that of sub-area 1. On a station-to-station basis the same type of distribution is evident: The stations yielding the greatest numbers of copepods also had the greatest number of fish larvae (see Fig. 14). In sub-area 3 where all the stations had numerically similar catches of copepods on the average, the fish were numerically low and varied only slightly from station to station.

It may be significant, however, that the spot, *Leiostomus xanthurus*; the anchovy, *Anchoa* sp. (probably *A. mitchilli diaphana*); and the Atlantic croaker, *Micropogon undulatus*, that constituted together 70 per cent of all the fish caught in the project area during this study, are also reported to be plankton feeders in the early stages of their life cycle (Darnell, 1961). The adults are less important in the economy of the plankton, since they usually eat bottom invertebrates or larger organisms. The adult anchovies, however, still rely on copepods as part of their food (Darnell, 1958).

Although there was no direct evidence, it is possible that the concentration of fish larvae at some of the stations may have resulted from the concentration of zooplankton at the same location.

MINOR COMPONENTS

The minor components of the plankton may be discussed in three groups.

Group 1 plankters were typical of low salinity waters of sub-areas 1 and 2 and may have had a fresh water origin. These included the parasitic branchiuran genus *Argulus*, a species of the parasitic copepod genus *Ergasilus*, and Cladocera of the family Chydoridae from Bayou Dupre of sub-area 1.

Group 2 plankters were those typically marine organisms taken in sub-area 3, especially *Centropages hamatus*, *Labidocera aestiva*, *Paracalanus crassirostris*, *Pseudodiaptomus coronatus*, and *Tortanus setacaudatus*. *Centropages hamatus* is a surface copepod with a wide temperature range. Deevey (1960) found it inside and outside the bays, with greater numbers in the open waters, occurring generally in the winter in warm waters.

Labidocera aestiva was one of the largest copepods encountered during the investigation. However, it did not form a very significant part of the copepod population. Wilson (1932a) noted that the presence of *L. aestiva* in Chesapeake Bay was only occasional while it was always present in the outside waters, often near the bottom. Grice (1956) suggested that *L. aestiva* reproduced in the waters outside Alligator Harbor. Gonzalez (1958) described *L. aestiva* as "fairly common throughout the year" off the mouth of the Mississippi River. *L. aestiva* was found in relatively large numbers in late summer, but migrated outside the bay shortly thereafter.

Paracalanus crassirostris increased in numbers in those stations under the influence of Breton Sound, suggesting that origin. In Great Pond, Falmouth, Barlow (1952) reported *P. crassirostris* in small numbers compared to the outside waters of Vineyard Sound. Gonzalez (1958) recorded increasing numbers of *P. crassirostris* sampling from a bay with restricted access to the offshore waters.

Pseudodiaptomus coronatus was reported by Wilson (1932) as a brackish-water species. Gonzalez (1958) encountered specimens at one station close to the Mississippi outflow. Fleminger (1956) found *P. coronatus* associated with *A. tonsa* and *L. aestiva* in the regions most subjected to land drainage. According to Grice (1956), *P. coronatus* inhabits the deeper waters during the daylight hours and migrates diurnally. In Alligator Harbor most of the specimens were caught in the evening. This might support the view that they live close to the bottom or burrow during the day. Deevey's (1960) conclusions were almost identical. There was evidence that the "female prefers deep water" and "possibly the major part of the *P. coronatus* population remained well below the surface."

This survey is apparently the first to report a significant number of *Tortanus setacaudatus* in the Gulf of Mexico region. Foster (1904) has a record of unidentified species of *Tortanus* taken near the Gulf Biological Station which might well be *T. setacaudatus*. Fleminger (1956) caught *T. setacaudatus* in only one sample at the entrance of Galveston Harbor.

In general, the samples with ctenophores or coelenterates contained fewer copepods than the others (Reid, 1955; Cuzon du Rest, 1959). Barlow (1952) has observed in Great Pond that the decrease in zooplankton population coincided both in 1950 and 1951 with the appearance of ctenophores. The number of *A. tonsa* rose sharply at all the stations of sub-area 3 both in the fall of 1959 and 1960 after the ctenophores had a seasonal decline. Two hypotheses are suggested: (1) either the ctenophores clog up the

net and reduce its filtering capacity (Davis, 1948); or (2) there is a biological interaction responsible for decrease in the zooplankton population (Deevey, 1960).

The majority of the echinoplutei was found near LAS, sub-area 3, suggesting that this sub-area might be used for breeding grounds.

Oikopleura dioica constituted only a small share of the plankton population.

Group 3 plankters were common to all three sub-areas. Harpacticoids were represented in all three sub-areas but were more numerous in sub-area 1. The Lake Borgne stations which had the largest numbers of *A. tonsa* and *E. hirundoides* had few or no harpacticoids.

Four species of cyclopoids were identified: (1) *Cyclops panamensis*; (2) *Cyclops vernalis*; (3) *Eucyclops agilis*; and (4) *Macrocyclus albidus*. The first two species were the most abundant. The cyclopoids were over sixteen times more numerous in sub-area 1, especially at RB and BD, than in sub-area 3. Sub-area 2 had the smallest numbers. The cyclopoids found in this investigation are reputed to be brackish-water forms (Yeatman in Ward and Whipple, 1959).

The number of polychaete larvae did not vary noticeably from one sub-area to the next nor from one station to another. The Lake Borgne stations, however, had smaller numbers than any other stations and fewer were caught in sub-area 1 than in the other two sub-areas.

Although shrimp larvae were ubiquitous, their highest numbers occurred in the high salinity stations close to Breton Sound.

Planktonic gastropods were too small to be adequately sampled by a #6 net. Specimens taken showed an increase in their population from sub-area 1 to sub-area 3.

Acknowledgments

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Oxygen Metabolism of Four Oklahoma Farm Ponds

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Abstract

Oxygen metabolism of four Oklahoma farm ponds was studied during the spring and summer of 1962. Gross photosynthetic productivity ranged between 4.4 and 27.4 gm O₂/m² per day and total community respiration ranged between 6.4 and 26.4 gm O₂/m² per day. These values are of the same magnitude or higher than those reported for similar unpolluted communities and only slightly less than those reported for polluted systems.

Introduction

Dotting the landscape of Oklahoma are numerous farm ponds of various sizes, morphologies and chemical characteristics. These ponds receive waters that have drained from rich and poor rangelands and farmlands. Relatively few studies have been made of the metabolism of this type of aquatic community. Most studies are on polluted streams and ponds, lakes, springs, and marine waters.

Some of the best sports fishing in Oklahoma are found in farm ponds, yet few efforts have been made to appraise their primary productivity. To obtain some idea of the magnitude of photosynthesis and community respiration, free-water oxygen methods were applied to four farm ponds near Stillwater, Oklahoma during the spring and summer of 1962.

Methods

The methods of Odum (1956) and Odum and Hoskin (1958) were followed to obtain the community metabolism. Depth of light penetration was determined with a submarine photometer, and was that depth at which light was 1% of surface intensity. Oxygen content was measured in duplicate every three hours by the Alsterburg modification of the Winkler method (A.P.H.A., 1960). Rate of change curves were corrected for exchange of oxygen between the water and the atmosphere as outlined by Odum (1956).

To ascertain the presence of stratification in the ponds, oxygen measurements were made at three depths and three positions in each pond on two different occasions (May 1 and 6, 1963). Typical wind conditions existed at the time of the measurements, i.e., 15 to 20 miles per hour on May 1 and less than five miles per hour on May 6. Oxygen con-

centration differed less than 0.5 mg/liter in Ponds 1, 3, and 4 for all samples, indicating little or no stratification. In Pond 2, however, oxygen concentration differed by as much as 2.5 mg/liter from surface to bottom, indicating stratification. Therefore, community metabolism reported in the following discussion is indicative of only the euphotic zone (as measured by 1% light penetration) for Pond 2 and is indicative of the whole pond in the unstratified ones.

DESCRIPTION OF THE PONDS

The four ponds, unnamed, so therefore, designated Ponds 1 through 4, were located in Payne County within one mile of Stillwater, Oklahoma. The ponds were chosen because they represent four of the common types found in the area. The ponds had a surface area of one-fourth acre (Ponds 1, 2, and 4) and one-half acre (Pond 3), and an average depth of one to two meters.

Pond 1 was located below the feedlot of a swine barn and received the waste products of the swine as well as leftover feed. Consequently the pond community was very fertile and supported a dense growth of *Spirogyra* sp. However, light often penetrated to the bottom of the pond, especially when a break in the vegetation occurred.

Pond 2, located about one-fourth mile east of Boomer Lake, drained about 40 acres of lush rangeland. The dominant vascular plant was *Najas guadalupensis* (naias). The planktonic algae were dominated by diatoms. The water was usually clear and the average measured depth of light penetration was about one to two meters.

Pond 3, located near the eastern city limits of Stillwater, drained about 80 acres of overgrazed, seriously eroded pastureland. The water was turbid with colloidal clay particles and light rarely penetrated below 0.6 meters. The principle vascular plant was *Jussiaea repens* (water-primrose). The planktonic algae were dominated by diatoms.

Pond 4, near highway 51 on the east side of Stillwater, received water from good grass cover and approximately one acre of chicken pens. The water was usually clear and light often penetrated to the bottom. The principal vascular plants were *Sagittaria* spp. (arrowheads) and *Najas guadalupensis* (naias). An extremely diverse and rich non-vascular flora was also present (attached and planktonic algae).

Oxygen Metabolism

Typical diurnal oxygen curves were obtained during the summer. A representative curve for turbid waters is shown in Fig. 1 for Pond 3, a pond turbid with colloidal clay from the eroded drainage area. A heavy cloud cover existed for the entire diurnal period and undoubtedly suppressed photosynthesis. The water was undersaturated during most of the diurnal period. Photosynthesis was about two-thirds of the total respiration (P/R ratio of 0.7).

A diurnal oxygen curve, representative of those obtained in Ponds 2 and 4 during summer, is presented in Fig. 2 for Pond 4 on August 18, 1962. The water was supersaturated during most of the daylight period. Photosynthesis was approximately the same as community respiration (P/R ratio of about 1.0). The agreement between replicate oxygen samples indicates continuous mixing.

Fig. 3 shows a typical diurnal curve for Pond 1 during spring. Photosynthesis increased during the day to a maximum in late afternoon. The steady increase during the afternoon is in contradiction to the usual diurnal curves presented elsewhere (Odum and

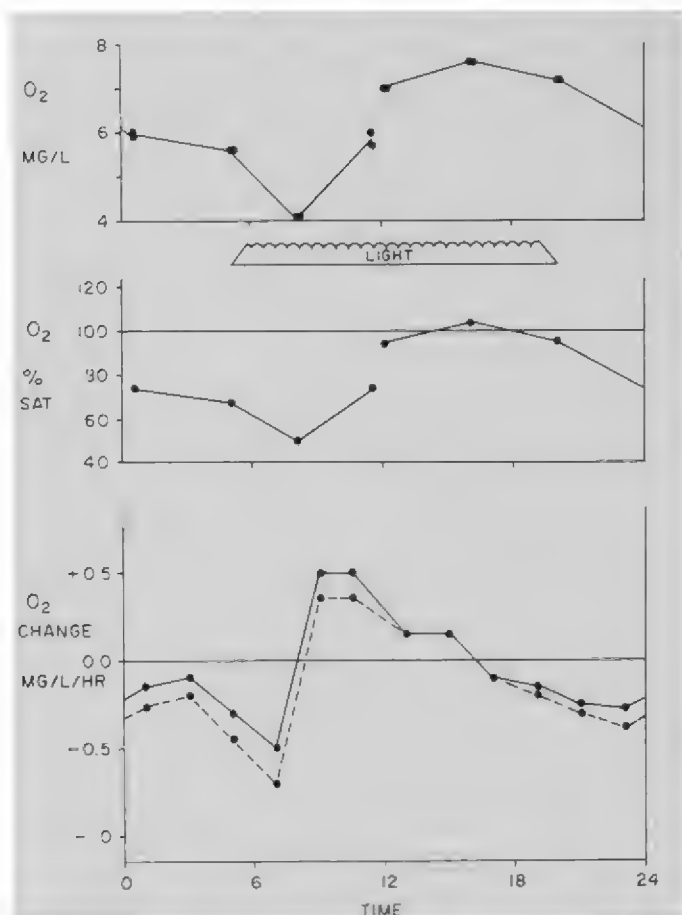


FIG. 1. Diurnal oxygen curve for Pond 3, June 27-28, 1962. The rate of change graph computed from the oxygen curve is plotted with a solid line; the graph of photosynthesis and respiration that resulted after subtraction of diffusion exchange is plotted with a dashed line. Points on oxygen curve represent duplicate samples.

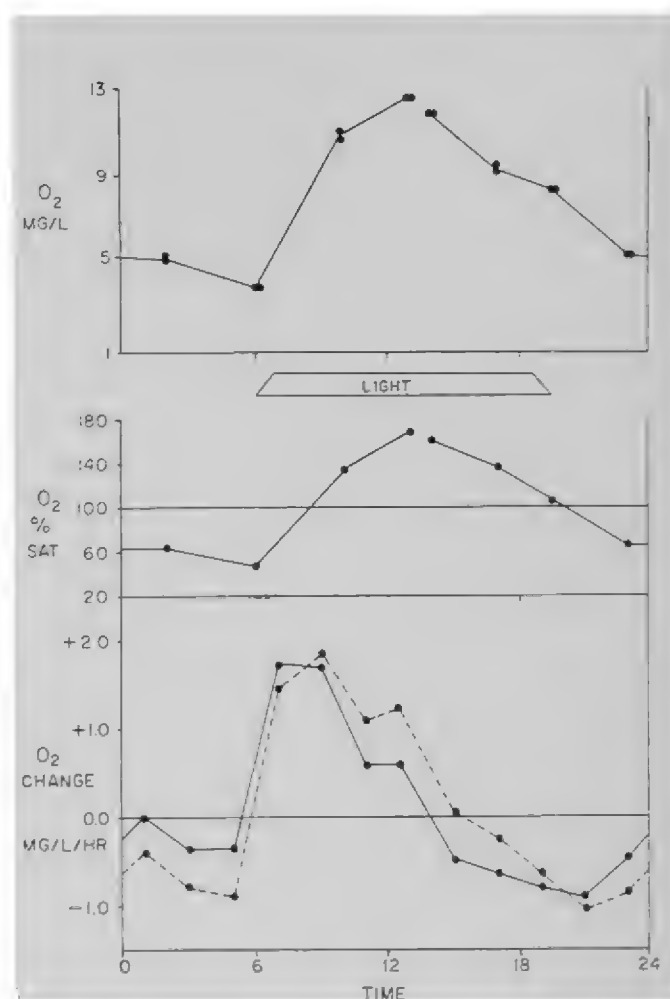


FIG. 2. Diurnal oxygen curve for Pond 4, August 18, 1962. See Fig. 1 for explanation of symbols.

Hoskin, 1958; Copeland, Butler and Shelton, 1961; Copeland and Dorris, 1962; and Beyers, 1963), and diurnal curves of the other ponds in this study (Figs. 1, 2, and 4). In those examples, the maximum rate occurred during the forenoon or early afternoon. The wide disagreement of replicate oxygen concentrations at the dawn sampling period indicates that stratification may have occurred at that time. Ice formed on the surface of the water between the 0300 and the dawn sampling time.

Data for the entire study, based on curves like those in Figs. 1, 2, and 3 are presented in Table 1. Gross photosynthetic productivity ranged between 4.4 and 27.4 gm O_2/m^2 per day and total community respiration ranged between 6.4 and 26.4 gm O_2/m^2 per day. Diffusion constants ranged from 0.2 to 2.8 gm O_2/m^2 per hour, within the range reported by Copeland (1963) for polluted ponds in the same area.

EFFECTS OF DECAYING VEGETATION

The decay of vegetation in Pond 2 during August resulted in an increase in community respiration (Table 1). Mr. John Hooser of the Aquatic Biology Laboratory, Oklahoma State University, experimented with some chemicals that resulted in the death of a large amount of the vegetation. Although some of the vegetation escaped death, a large amount of it settled to the bottom, out of the effective light zone, and required oxygen for its respiration and decomposition. The P/R ratio decreased from near unity during the previous sampling times to about 0.5.

Fig. 4 shows diurnal curves before and after the vegetation kill. In April, clouds during

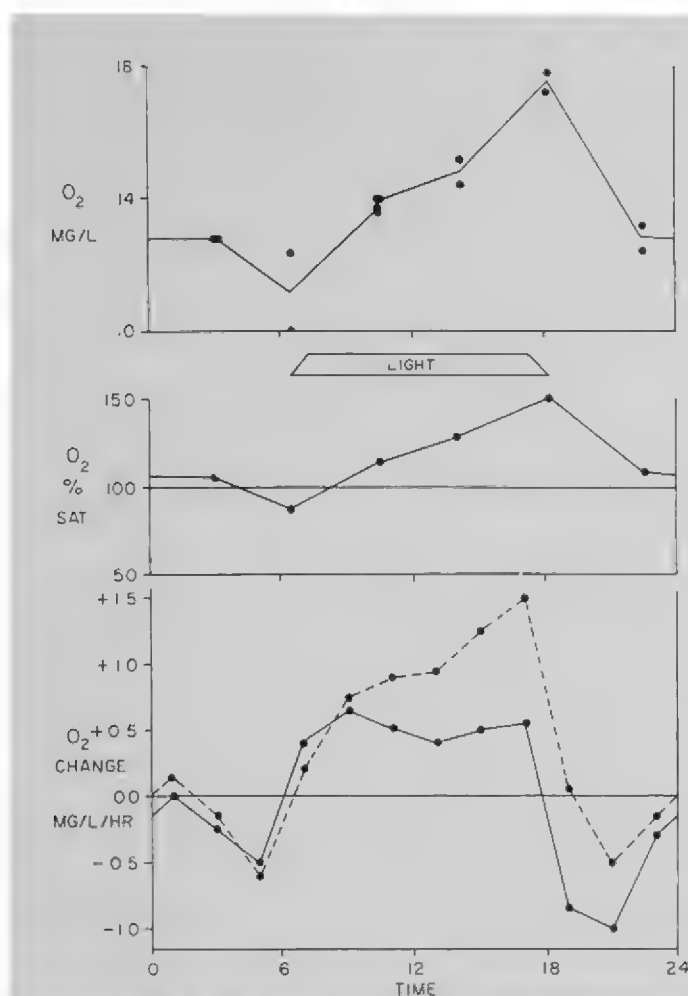


FIG. 3. Diurnal oxygen curve for Pond 1, March 15-16, 1962. See Fig. 1 for explanation of symbols.

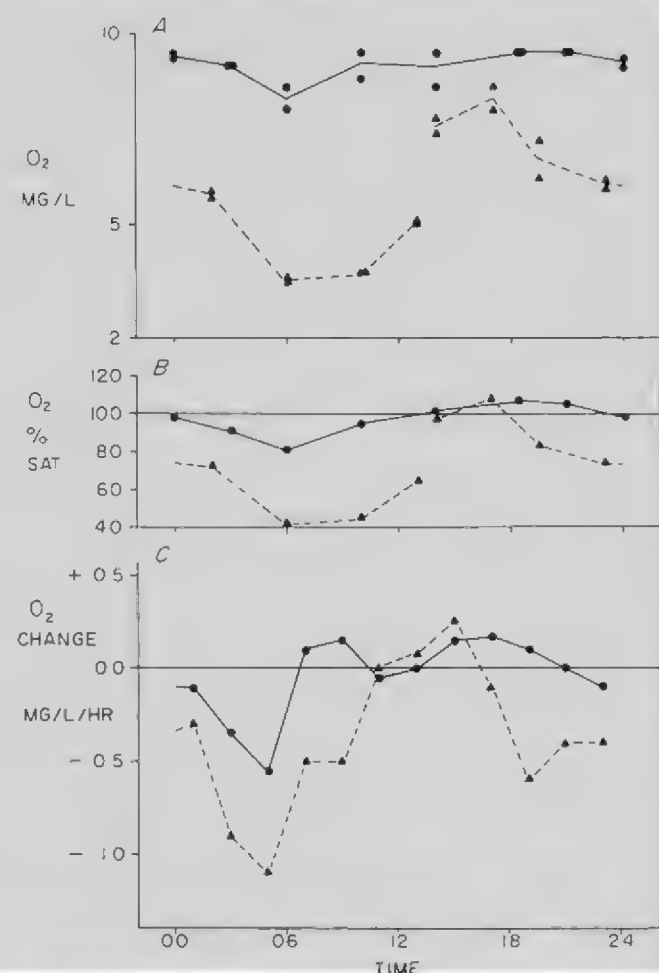


FIG. 4. Diurnal oxygen curves for Pond 2 before and after the vegetation was killed by chemicals. The curve before the vegetation kill was taken on April 18, 1962 and is indicated by the solid line. The curve after the vegetation kill was taken on August 18, 1962 and is indicated by the dashed line. Graph A is the observed oxygen concentration, graph B is per cent saturation, and graph C is the rate of change corrected for diffusion.

midday caused a depression in the photosynthetic rate, otherwise the diurnal curve indicated by a solid line in Fig. 4 was typical of the curves presented by other authors. The diurnal curve after the vegetation kill (dashed curve in Fig. 4) was much like those

TABLE I
Oxygen metabolism of Oklahoma farm ponds

Pond	Date	Light depth in meters	Diffusion Constant gm O ₂ /m ² per hour	Metabolism in gm O ₂ /m ² per day		
				P	R	P/R
Pond 1	3/15-16/62	0.90	1.6	17.8	10.8	1.7
	4/18/62	0.90	0.3	8.0	7.4	1.1
	6/27-28/62*	0.77	0.8	8.8	8.4	1.0
Pond 2†	4/18/62	2.00	2.8	13.3	15.6	0.9
	6/27-28/62*	1.08	0.6	6.0	7.8	0.8
	8/18/62	1.30	1.3	12.0	23.4	0.5
Pond 3	6/27-28/62*	0.51	0.2	4.4	6.4	0.7
	8/18/62	0.62	0.6	5.7	8.2	0.7
Pond 4	6/27-28/62*	0.75	0.3	8.1	10.1	0.8
	8/18/62	1.20	1.4	27.4	26.4	1.1

* Heavy clouds throughout the diurnal period.

† Stratified at least through the daylight hours; metabolism of upper layer only.

found in polluted waters (Copeland and Dorris, 1962; and Copeland 1963). The slow increase during early daylight hours apparently was the result of oxidation of chemical compounds reduced during the nighttime low oxygen concentrations or the fulfillment of oxygen debts incurred during the night. The reduction of oxygen concentration must be considered when anticipating the use of chemicals to rid the farm pond of vegetation, otherwise a fish population may be lost when the decaying vegetation uses the oxygen normally available for fish respiration.

EFFECT OF A HYPOLIMNION EXPORT SYSTEM ON COMMUNITY METABOLISM

Photosynthetic productivity occurs only in the effective light penetration zone; in the case of the stratified pond in this study (Pond 2) the epilimnion. Respiration or oxygen demand occurs in both the euphotic zone and the dark zone (including the bottom). If a body of water is continually stratified, the leak of oxygen from the photosynthetically active zone into the stagnant hypolimnion is constant as physical conditions dictate. However, if the body of water is stratified during the day and mixing during the cooler night the drain of oxygen is intensified during the night. If, in that sort of situation, the oxygen concentration is measured diurnally, the true metabolism of the epilimnion is erroneously measured, especially during the night. The hypolimnion acts as a huge drain on the epilimnionic oxygen supply during the night and lies in waiting during the day.

The increased respiration observed between midnight and dawn in Pond 2 (Fig. 4) may be attributed to mixing of the epilimnion and hypolimnion at night following stratification during the day. From just after dawn until midnight, metabolism of the epilimnion was measured but after that time the oxygen demand of the entire water mass mixing together caused the oxygen concentration (as measured in the epilimnion) to decrease at a more rapid rate than during the previous period. This problem could be solved by taking samples at several depths at frequent intervals.

Comparison With Other Communities

The gross photosynthetic productivity range of 4.4 to 27.4 gm O₂/m² per day and total community respiration range of 6.4 to 26.4 gm O₂/m² per day are of the same order of magnitude or higher than similar communities. Copeland *et al.* (1961) reported 1.1 to 7.3 gm O₂/m² per day photosynthesis and 4.6 to 9.5 gm O₂/m² per day respiration in a small pond on the Oklahoma State University campus. Odum and Hoskin (1958) reported 2.2 to 4.5 gm O₂/m² per day photosynthesis and 2.1 to 5.2 gm O₂/m² per day respiration in Stewart Farm Pond in North Carolina. Minter and Copeland (1962) observed photosynthesis of zero to 5.9 gm O₂/m² per day and respiration of 8.9 to 49.6 gm O₂/m² per day in a pond in Kansas. The high respiration value occurred after a heavy leaf fall in the adjacent area and was undoubtedly caused by their decay. Sitaramiah (1961) reported photosynthetic productivity values of 5.7 to 8.6 gm O₂/m² per day for the Tatayya gunta pond in southern India.

Higher productivity and respiration have been reported for polluted waters. Odum (1956) reported a photosynthetic productivity of 60 gm O₂/m² per day in the polluted White River, Indiana. Copeland and Dorris (1962) reported photosynthesis as high as 23.4 gm O₂/m² per day and respiration of 30.2 gm O₂/m² per day in ponds polluted with oil refinery effluent. Copeland (1963) reported photosynthesis of 29.2 gm O₂/m² per day

and respiration of 50.5 gm O₂/m² per day in oil refinery effluent holding ponds. Photosynthesis of 36 gm O₂/m² per day and respiration of 36 gm O₂/m² per day have been reported for sewage oxidation ponds in South Dakota (calculated from Bartsch and Allum, 1957).

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We acknowledge and appreciate the assistance of Mr. John L. Butler of the Aquatic Biology Laboratory at Oklahoma State University, Stillwater, Oklahoma. The facilities and equipment of the Aquatic Biology Laboratory were used during the study. Dr. H. T. Odum, Institute of Marine Science, University of Texas, Port Aransas, Texas, criticized the manuscript.

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New Additions to the Bryozoan Fauna of the Gulf of Mexico

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Abstract

This paper deals with thirty-four species of bryozoa which had not been before recorded from the Gulf of Mexico and the north side of the Straits of Florida. These new additions to the fauna bring the total number of Bryozoan species recorded from the area under consideration to 216.

Six other species, already previously known, are also discussed on account of taxonomical or zoological questions involved. They are marked with an asterisk in the following list.

List of species recorded in this paper

<i>Aetea anguina</i>	<i>Hippopodina bernardi</i> sp. nov.
<i>Membranipora tenuissima</i>	<i>Arthropoma cecilii</i>
<i>Conopeum commensale</i>	* <i>Cribellopora trichotoma</i>
<i>Electra monostachys</i>	<i>Escharina vulgaris</i>
<i>Electra bellula</i>	* <i>Cleidochasma contracta</i>
<i>Antropora typica</i>	<i>Hippoporella gorgonensis</i>
<i>Setosellina göesi</i>	<i>Hippodiplosia americana</i>
* <i>Retevirgula tubulata</i>	<i>Exochella longirostris</i>
<i>Parellisina latirostris</i>	<i>Smittoidea reticulata</i>
* <i>Chaperia patula</i>	<i>Codonellina montferrandii</i>
<i>Floridina parvicella</i>	<i>Parasmittina signata</i>
<i>Monoporella divae</i>	<i>Phoceana acadiana</i> sp. nov.
<i>Setosella vulnerata</i>	<i>Lekythopora longicollis</i> sp. nov.
<i>Euginoma cavaleri</i> sp. nov.	<i>Crepidacantha poissonii</i> var. <i>teres</i>
<i>Beania hirtissima</i>	<i>Vittaticella uberrima</i>
<i>Scrupocellaria harmeri</i>	<i>Halysisis diaphana</i>
<i>Caberea boryi</i>	* <i>Fedora nodosa</i>
<i>Figularia contraria</i> sp. nov.	* <i>Crisulipora occidentalis</i>
<i>Bellulopora bellula</i>	<i>Stomatopora trahens</i>
<i>Chorizopora brongniartii</i>	<i>Idmidronea flexuosa</i>

Introduction

In view of the amount of previous work on the subject, one might suppose the bryozoan fauna of the Gulf of Mexico to be one of the best known in the world. Recently Osburn

(1954), in a summary of the state of our knowledge gained over a period of almost 90 years, arrived at a total of 170 species of Bryozoa known from the Gulf. The addition, through this paper, of 34 species which had so far escaped notice in this area would seem all the more surprising. For a better understanding it is necessary to realize with Osburn (1954, p. 362) that the existing collections were made almost entirely from the Eastern Gulf of Mexico. In fact most of the collecting was done in an even more restricted area near the southern end of the Florida Peninsula. Hitherto only eight species have been recorded from the Western Gulf, *Nellia oculata* (Levinsen, 1909, p. 121), *Conopeum tubigerum* (Osburn, 1940, p. 352), *Membranipora tuberculata*, *Acanthodesia savartii*, *Bugula turrita*, *Bugula neritina* (Hedgpeth, 1950, p. 84), *Membranipora flabellata* (Ladd, 1951, p. 139) and *Acanthodesia tenuis* (Ladd, Hedgpeth and Post, 1957, p. 615). Most groups of marine organisms (the Foraminifera are a notable exception) appear to suffer from this lack of data from the Western Gulf, as one gathers from the various contributions in "Gulf of Mexico, its Origin, Waters and Marine Life," edited by Galtsoff (1954). More than half of our new records come from this unexplored area. The geographical term "Gulf of Mexico" has here been taken in the restricted sense proposed by Galtsoff (*l.c.*, p.v), *i.e.* as having the line Cabo Catoche—Key West as its southeastern boundary. The dividing line between the Eastern and the Western Gulf of Mexico in this paper coincides with the meridian of 89° W.

A second source of new finds was located in a very different sector. Nearly all the marine bottom samples investigated (Appendix) were not available to the author in their original state, but as washed residues. Such residues are obtained by washing a given amount of the sample over a set of sieves with progressively diminishing mesh-size, a routine procedure in the preparation of samples for foraminiferal analysis. It is not the first time that scanning the finer residue fractions, notably the 250–590 μ fraction, has provided the author with a number of small-sized species which had previously remained unnoticed in a fauna (Lagaaij, 1959). The new Gulf records of the genera *Chorizopora*, *Vittaticella* and *Halysisis* owe their presence in this paper to their showing up in these finer residue fractions.

Osburn's total number of 170 species needs correction in several ways. Primarily the restriction of the term "Gulf of Mexico" (see above) excludes a number of species from his survey, *viz.* those recorded from the shallow platform E of the Yucatan Peninsula (Canu and Bassler, 1928a), and those from the deeper waters N of Cuba (De Pourtales, 1867; Smitt, 1872, 1873; Canu and Bassler, 1928a). Nevertheless, perusal of the pertinent literature gives a slightly larger figure, as the following breakdown will show:

De Pourtales (1867)	1	Hastings (1932)	1
Smitt (1872, 1873)	89	Osburn (1940)	3
Hincks (1880b)	2	Hastings (1943)	1
Busk (1884)	1	Osburn (1947)	2
Osburn (1914)	41	Silén (1947)	1
Canu and Bassler (1928a)	40		
		TOTAL	182

In this list the figure after each name indicates the number of species which constitute new Gulf records by the respective author, whether given under their proper name or not. Osburn (1914), for instance, who listed a total of 78 species from the Tortugas, included 41 species which had not been previously known to De Pourtales, Smitt, Hincks, or Busk. In drawing up this list allowance was made for those cases in which authors included two or more different forms under one name, or in which one species has been given under two different names by the same author.

Thirty-four species are here described which had not before been recorded from the Gulf of Mexico and the north side of the Straits of Florida. This brings the total number of known Gulf species to 216, a figure comparable with that established for Brazil (Marcus, 1953). In both areas the deeper waters, beyond the 100 or even the 50 fathom isobath, remain virtually unexplored.

The types and the figured specimens have been deposited in the Department of Geology, United States National Museum, Washington, D.C. The corresponding USNM catalogue numbers are given in the text and in the Index to Plates.

There is a second group of catalogue numbers, each number consisting of four ciphers separated by full stops; these are used in the text without additional explanation and refer to specimens kept in the Department of Zoology of the British Museum (Natural History).

Systematics

Family AETEIDAE SMITT, 1867

Genus *Aetea* Lamouroux, 1812

Aetea anguina (Linnaeus)

(Pl. VIII, Fig. 1)

Sertularia anguina Linnaeus (1758, p. 816).

Aetea anguina Busk (1884, p. 2), Duerden (1896, p. 270), Robertson (1905, p. 244, pl. 4, figs. 1-4), Osburn (1912, p. 220, pl. 21, figs. 14, 14a), Marcus (1921, p. 114, text-fig. 15), O'Donoghue and O'Donoghue (1926, p. 85), Hastings (1930, p. 702), Osburn (1933, p. 306, pl. 15, fig. 12), Marcus (1937, p. 26, pl. 5, fig. 8), Osburn (1940, p. 345, pl. 1, fig. 8), Hastings (1943, p. 471, text-figs. 57a-c), Osburn (1944, p. 28, text-fig. 17), Osburn (1950, p. 11, pl. 1, fig. 3), Marcus (1953, p. 278, *cum syn.*), Maturo (1957, p. 32, text-fig. 24), Soule (1959, p. 2).

Material

Locality 64. Several colonies, incrusting around unidentified flexible stems. Washed ashore.

Occurrence

North-western Gulf: Galveston Island, Texas.

American distribution

Mount Desert Island, Maine	5-6 $\frac{2}{3}$ fathoms
Woods Hole, Mass.	1-19 fathoms
Mouth of Chesapeake Bay, Virginia	2 fathoms
Beaufort, North Carolina	
Bermuda	30 fathoms

Guanica Harbor, Puerto Rico	10 fathoms
Kingston Harbour, Jamaica	
Bay of Santos, Guarujá, etc., Brazil	0-17 metres
Espírito Santo, Brazil	35 metres
Patagonia	50-80 metres
Falkland Islands	74-75 metres
Chili	45 fathoms
Juan Fernandez Islands	
Peru (-Oregon)	0-30 fathoms
Galapagos Islands	5-12 fathoms
Gulf of California	0-22 fathoms
California	
Oregon (-Peru)	0-30 fathoms
British Columbia	10-15 fathoms

American fossil distribution

Upper Eocene (Ocala Limestone) of Ocala, Florida and of Bainbridge, Georgia.

Family MEMBRANIPORIDAE BUSK, 1854

Genus *Membranipora* De Blainville, 1830

Membranipora tenuissima Canu

(Pl. 1, fig. 2)

Membranipora tenuissima Canu (1908, p. 253, pl. 2, figs. 9, 10).

Material

Locality 4(1), 31(1), 109(1), 226(1).

Fossil material

Pleistocene of Shell-Continental Federal Block A-72, High Island Area, offshore well; 1210-1240' (ditch cuttings). 1 specimen. *Ibidem*, 1270-1300' (ditch cuttings). 1 fragment.

Remarks

The most distinctive feature is the remarkable partial closure of the apertural area in some zooecia, brought about by marginal calcification underneath the ectocyst. In these partially occluded zooecia the former position of the operculum is outlined by a $\cap$ -shaped shallow depression in the distal part of the calcified area.

I am grateful to Dr. Anna B. Hastings, who has brought Canu's description and figures of *M. tenuissima*, from the Post-Pampean of the Argentine, to my attention. The partially occluded zooecia with their characteristic distal depression shown by Canu are unusual among Recent Membraniporidae so that the odds are in favour of this being indeed the same species. It is probable that these arcuate impressions have not received their full proximal extension on Canu's touched-up photographs. They now appear too shallow to fit the distal outline of the operculum.

Of the two pairs of septula in the lateral walls of the zooecia, the distal ones tend to be larger, and to become more conspicuous with increasing irregularity of incrustation. Zooeciules, always associated with irregular incrustation, are particularly common in

the specimen from Grand Isle, Louisiana, which is found encrusting a multilamellar colony of *Conopeum commensale*. A row of widely spaced spine bases, to a maximum of five on each side, is sometimes placed along the zooecium near the interzooecial groove. They are present, although not on all zooecia, in the more complete specimens from Grand Isle, Corpus Christi Bay, and from the Federal Block A-72 offshore well (1210–1240' and 1270–1300').

In two of our specimens, viz. from Cavalier Station 2 and from the Federal Block A-72 offshore well (1270–1300') two successive growths are apparent in the calcareous closure, which suggest that calcification took place in stages. Rows of unequally spaced small dots are present on the boundary line between these growth stages and the question has arisen whether these markings are the bases of small apertural spines or just pores in the calcareous closure. I agree with Dr. Hastings, who has kindly examined the specimens, that the latter possibility is more likely.

The distributional picture one gathers from the Gulf coast is that this species is clearly confined to the very shallow brackish inshore and offshore waters. The fragmentary Sabine Bank specimen from Locality 109, taken at 12 $\frac{1}{3}$ fathoms, seems to contradict this conclusion. It differs markedly in preservation, however, from the rest of the assemblage collected at this locality. This fragment, therefore, probably did not occur *in situ*, but is interpreted as derived from brackish coastal deposits associated with the coastline of one of the rising sea level stages during the Early Holocene.

Occurrence

North-western Gulf:	
Corpus Christi Bay, Texas	2 $\frac{2}{3}$ fathoms
Off Freeport, Texas	6 $\frac{2}{3}$ fathoms
Sabine Bank	12 $\frac{1}{3}$ fathoms
Gulf beach of Grand Isle, Louisiana	

Fossil occurrence

Pleistocene of Shell-Continental Federal Block A-72, High Island Area, offshore well, 1210–1240' (ditch cuttings); *ibidem*, 1270–1300' (ditch cuttings).

Fossil distribution

Post-Pampean (Holocene), Puerto Militar, Bahía Blanca, Argentine.

Genus *Conopeum* Gray, 1848

Conopeum commensale Kirkpatrick and Metzelaar (Pl. VIII, fig. 2)

Conopeum commensale Kirkpatrick and Metzelaar (1922, p. 985, pl. 1, fig. 1, 4–6, 9), Marcus (1937, p. 35, pl. 5, fig. 13), Marcus (1938a, p. 16, pl. 3, figs. 6a–c), Marcus (1939, p. 126, pl. 6, figs. 5a–b, 6), Osburn (1950, p. 30, pl. 2, figs. 12–15), Soule and Duff (1957, p. 91), Maturo (1957, p. 36, text-fig. 29), Soule (1959, p. 7). *Membranipora fusca* Canu and Bassler (1925, p. 11, pl. 2, figs. 6–8).

Material

Locality 4(9), 5 (several), 10(1), 13(6), 26(1), 28 (several on gastropod), 36(1), 60–63, 65 (several), 67(1), 77(4), 78(1), 86(1), 108(4), 110(2), 120(1), 126(8), 132(1), 226(2).

Remarks

The following criteria serve to identify this species: the thick, multilamellar incrustation on gastropod and pelecypod shells, the fusion of the gymnocystal tubercles into prominent "rectangular blocs" in the older zooecia, the thin dark brown lines marking the zooecial boundaries, the great distance between the frontal and dorsal walls, and the occasional presence of chitinous spinules on the frontal membrane. Unfortunately, these characters are seldom united in one specimen.

Multilamellar incrusting specimens are at hand from the Gulf beaches of Grand Isle, Louisiana, and Galveston Island, Texas. Those available from St. Joseph Island, Texas, are either unilamellar incrusting, or growing upward in pseudovinculariiform growth around unidentified flexible stems. In the Cavalier grab-samples from the inner part of the continental shelf several smaller fragments occur, which I believe also belong to this species. They are characterised by the great distance between the frontal and dorsal walls and/or by the "brown lines" of the original description.

This appears to be a common inner neritic species in the North-western Gulf of Mexico, where salinities are somewhat reduced and subject to seasonal variation. It has not been found on the shelf of peninsular Florida, where open Gulf salinities ($> 35\text{‰}$) extend practically up to the beaches and remain remarkably constant throughout the year (Fig. 1).

Occurrences

North-western Gulf:

Corpus Christi Bay, Texas; NW Gulf of Mexico beaches from St. Joseph Island,

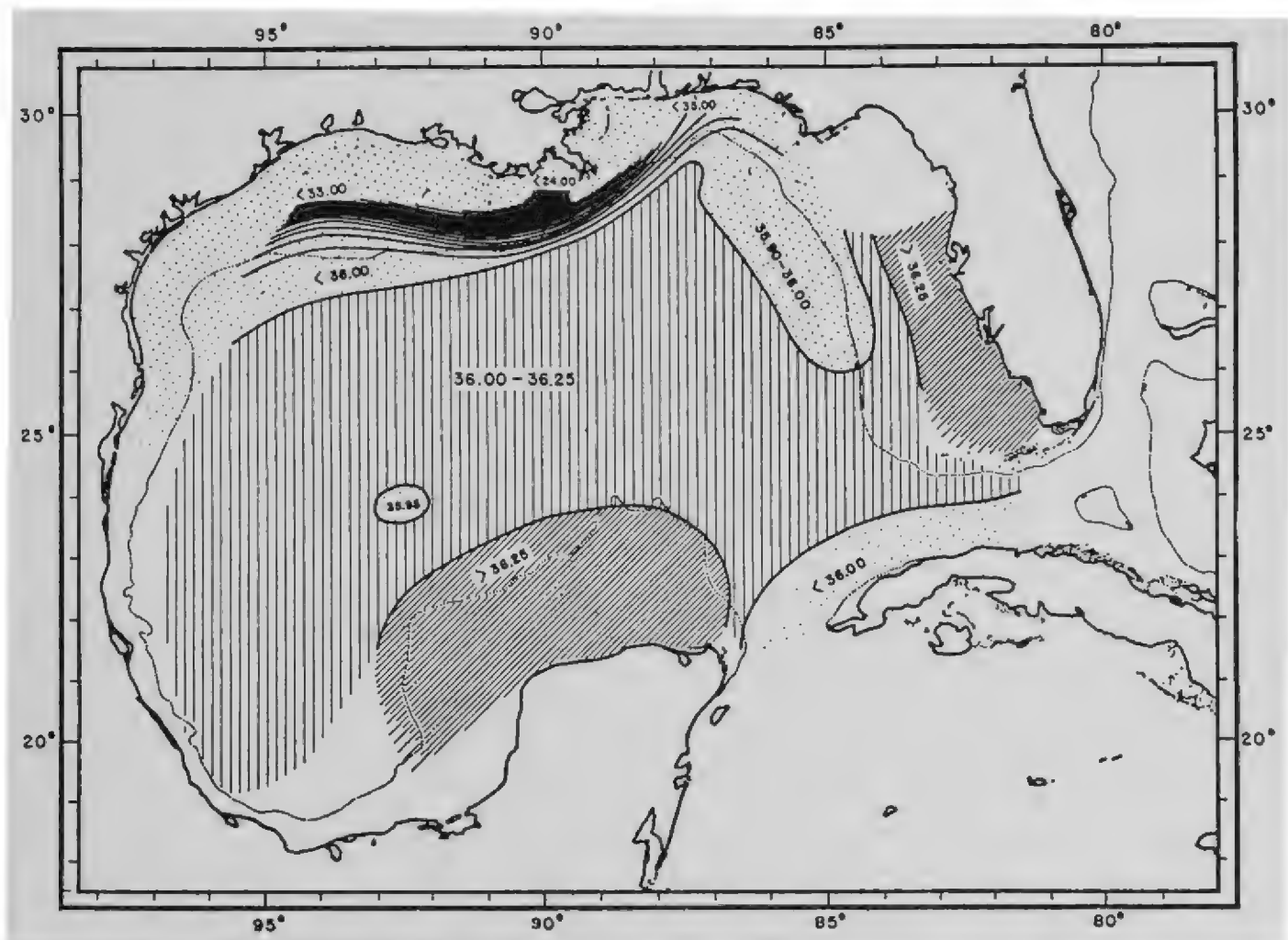


FIG. 1. Distribution of average salinities in the upper 50 metres in the Gulf of Mexico (after Parr, 1935).

Texas to Grand Isle, Louisiana; and at various offshore stations in the NW Gulf 0–20 fathoms.

Distribution

Cape Blanco, West Africa	5–10 fathoms
Port Etienne, Mauritania	
Beaufort, North Carolina	6½ fathoms
Bay of Santos; Guarujá; Itanhaen, Brazil	} in shallow water and on the beaches
Gulf of California	
	5–40 fathoms
Pacific Coast of America from Lower California (Mexico), Costa Rica, and La Plata Island, Ecuador	2–45 fathoms

Fossil distribution

Pleistocene of Newport, California.

Family ELECTRIDAE STACH, 1937

Genus *Electra* Lamouroux, 1816

Electra monostachys (Busk)

(Pl. I, fig. 1)

Membranipora monostachys Busk (1854, p. 61, pl. 70, figs. 1–4), Jullien (1881, p. 168), Calvet (1904, p. 13), Osburn (1912, p. 227, pl. 22, figs. 29, 29a; *non* pl. 22, fig. 29b, pl. 30, fig. 87 = *E. crustulenta* (Pallas), var. *aretica* Borg).

Electra monostachys Canu and Bassler (1923, p. 17, *partim*, pl. 29, figs. 2, 3, *non* 1), Hastings (1930, p. 706), Osburn (1933, p. 20, pl. 15, fig. 13).

Electra hastingsae Marcus (1937, p. 39, 40), Marcus (1938a, p. 17, pl. 2, fig. 7), Osburn (1944, p. 39, text-fig. 24, *cum syn.*), Rogick and Croasdale (1949, p. 55, figs. 27, 28), Osburn (1950, p. 38), Maturo (1957, p. 38, text-fig. 31).

Material

Locality 5(1), 16 (1, markings on shell fragment only), 23(1), 55(1), 60–63 (several), 119(1).

Fossil material

Pleistocene of Western Natural Gas Company offshore well, St. Tr. 608#1, Matagorda Area, Texas, 410–440' (ditch cuttings). 1 specimen.

Remarks

The mode of incrusting in *E. monostachys* is usually monoserial-pluriserial. The sheetlike incrustation observed in our figured specimen from Galveston Island is rare and has only been reported from the Bay of Santos, Brazil (Marcus, 1938a, p. 17).

It is interesting to observe, in the same specimen, that whereas most of the apertural spines are still intact the stouter, erect ones: the distal pair flanking the orifice and the single median spine on the proximal gymnocyst tend to break off more easily than the more delicate paired incurved spines which line the lateral borders.

The distribution pattern of *E. monostachys* along the Texas and West Louisiana coast

confirms the habitat already on record in the literature: it is a species typical of the very shallow inshore waters of somewhat reduced salinity, such as found in the mouth of rivers, in estuaries, bays and inlets. In the original description of *E. monostachys*, Busk (1854, p. 61) gives the British habitat of the species as "Britain (east coast?). In the mouths of rivers and estuaries, [or in brackish water], spreading upon shells and stones, [sometimes erect, free, foliaceous and contorted]." Dr. Anna B. Hastings has informed me (*in litt.*), that the bracketed parts of this sentence refer to the specimen found by Mr. Higham (see Busk, 1854, p. 62) which belongs to *E. crustulenta* and (unpublished information) came from a brackish ditch. The greatest recorded depth of *E. monostachys* is 35 m (19 fathoms).

It is interesting to consider the North American distribution of the species (Fig. 3). In spite of the fact that the faunas around southern Florida have been rather extensively studied in the past, *E. monostachys* has never been recorded from that region. It is also conspicuously absent among the shallow assemblages of Tampa Bay, Fla., which were studied in some detail by the author. Along the North America Atlantic coast the species has been observed at a number of localities between the Mount Desert, Maine region and Beaufort, North Carolina, but not south of the last mentioned locality.

The resulting discontinuity along the North American coastline suggests that in the NW Gulf of Mexico *E. monostachys* is a Pleistocene relict form, which has survived since Pleistocene times only in the inshore waters of the Texas and West Louisiana coast. A prerequisite for this interpretation is that the species should have inhabited the Gulf area in Pleistocene times. Direct proof for this is the occurrence of *E. monostachys* in the Pleistocene of the Texas offshore region: Western Natural Gas Company, St. Tr. 608 #1, Matagorda Area, Texas, 410-440' (ditch cuttings).

Pleistocene relict forms in the NW Gulf of Mexico are well known among several other groups of marine organisms, notably the hydroids (Deevey, 1950), gorgonians (Bayer, 1954) and fishes (Rivas, 1954). This is the first time that they are recognized as such among the Bryozoa in this area.

Some authors assume that these disjuncts have survived because of the warm-temperate rather than tropical or subtropical winter temperature of the shallow water in this part of the Gulf of Mexico (Ekman, 1953, p. 55) and that the discontinuity around the Florida Peninsula is caused by a thermal barrier (Deevey, 1950). Since the disjunct Bryozoa are typically brackish (polyhaline) species, I have argued elsewhere in this paper (p. 194) that the barrier to free dispersal around the Florida Peninsula is perhaps of a saline rather than a thermal nature.

Occurrence

North-western Gulf:

Corpus Christi Bay, Texas	5/6 fathoms
off Freeport, Texas	4-8 5/6 fathoms
Gulf beach of Galveston Island, Texas	
Sabine Bank	7 fathoms

Fossil occurrence

Pleistocene of Western Natural Gas Company offshore well, St. Tr. 608 #1, Matagorda Area, Texas, 410-440' (ditch cuttings).

American distribution

Mount Desert Island, Maine	
Woods Hole, Mass.	2-19 fathoms
New Rochelle, New York	on <i>Fucus</i> and <i>Laminaria</i>
New Jersey	
Ocean City, Maryland	
Chincoteague Bay	
Mouth of Chesapeake Bay, Virginia	
Beaufort, North Carolina	
Balboa, Panama Canal Zone	Low tide level
Bay of Santos, Brazil	on <i>Mytilus</i> in shallow water
Magellan	

American fossil distribution

Pliocene of South Carolina
Pleistocene of Santa Barbara, California

Electra bellula (Hincks)

Membranipora bellula Hincks (1881a, p. 149, pl. 8, fig. 4).

Electra bellula Marcus (1937, p. 37, pl. 6, figs. 14A, B, D, E, F, *non* fig. 14C = var. *bicornis* Hincks), Osburn (1940, p. 355), Marcus (1953, p. 280).

Remarks

Dr. A. B. Hastings has found a small specimen of *E. bellula*, associated with *Electra tenella* (Hincks) and *Biflustra savartii* (Audouin), on the type slide of *E. tenella*: 99.5.1.648, Hincks Coll., from Florida, "on weed (Miss Jelly)," depth not indicated. In the North-western Gulf of Mexico *E. tenella* and *B. savartii* are both found in the inner neritic zone (0-120'), where salinities are normally somewhat reduced and subject to seasonal variation. Therefore there is some reason to believe that the "weed" was obtained from an estuary or lagoon, in shallow water of somewhat reduced and variable salinity, rather than off peninsular Florida where ocean salinities extend practically up to the beaches.

The distribution, as given below, was largely compiled from the records in the species register (Polyzoa) in the Zoological Department of the British Museum (N.H.), and does not include the varieties *bicornis* Hincks and *multicornis* Hincks.

Occurrence

Florida (99.5.1.648, Hincks Coll.)

Distribution

Australia
Indian Ocean
Red Sea
Madagascar
Cape Verde Islands
Puerto Rico

Pernambuco, Brazil
Espírito Santo, Brazil
Bay of Santos, Brazil

Family HINCKSINIDAE CANU AND BASSLER, 1927

Genus *Antopora* Norman, 1903

Antopora typica (Canu and Bassler)

(Pl. I, fig. 3)

Membrendoecium strictorostis Canu and Bassler (1928a, p. 23, pl. 2, fig. 7).

Dacryonella typica Canu and Bassler (1928a, p. 57, pl. 5, figs. 4–8, pl. 32, figs. 11–12),
Canu and Bassler (1928c, p. 65, pl. 1, fig. 10).

Canua typica (Canu and Bassler) Osburn (1940, p. 358).

Material

Locality 94(1), 150(8), 379(3), 411(1), 444(2).

Remarks

It is reasonably certain that Canu and Bassler in their Gulf of Mexico paper (1928a) described a Cuban deeper water species under two different names: *Membrendoecium strictorostis* and *Dacryonella typica*. This view is supported by the combination of the following facts:

1. According to modern views (cf. Osburn, 1950, pp. 51–52) both forms are now referable to *Antopora* Norman, 1903, and therefore at least congeneric.
2. The single occurrence of *M. strictorostis* was at Albatross Station D.2319, north of Cuba, 143 fathoms. *D. typica* was recorded from the same sample.
3. The two forms correspond in detail such as in the aspect of the small entozoecial ovicell and in form, size, position and orientation of the avicularia.

It would seem appropriate to retain the specific name of the form figured in most detail, which is *typica*.

Although this species is normally found encrusting a solid substratum, the two specimens taken SSW of John's Pass, Florida in 34 fathoms are pseudovinculariiform, *i.e.* consist of erect, hollow-cylindrical branches.

Occurrence

North-western Gulf: Cavalier 1956 Station 316	50 fathoms
Cavalier 1956 Station 278	38 fathoms
Eastern Gulf: Atlantis 1951 Station 154	64 fathoms
Vema-3 1954 Dredge #1	117 fathoms
SSW of John's Pass, Florida	34 fathoms

Distribution

North of Cuba	130–167 fathoms
Off Campos, Brazil	70 fathoms

Fossil distribution

Pliocene of Bocas Island, Almirante Bay, Panama

Genus *Setosellina* Calvet, 1906

Setosellina goësi (Silén)

(Pl. II, fig. 1)

Heliodoma goësi Silén (1942, p. 2, pl. 1, figs. 3, 4).

Vibracellina caribbea Osburn (1947, p. 11, pl. 1, figs. 1, 2).

Material

Locality 89(2), 99(2), 102(1), 109(1), 150(6), 179(63), 181(2), 354(3), 357(2), 358(3), 359(6), 360(4), 361(19), 363(1), 367(43), 369(1), 377(4), 379(1), 380(24), 381(13), 382(33), 383(72), 384(20), 385(97), 389(1), 390(1), 391(12), 392(30), 393(4), 395(2), 411(37), 412(7), 417(4), 442(4), 443(5), 444(5), 458(1), 458a(1), 461(1), 464(13), 465(1).

Remarks

The two "concentric" spirals of zooecia springing from the ancestrula described by Silén are easily recognized in juvenile specimens. Both left and right rotational spirals occur. The bispiral arrangement in the ancestrular region is also apparent in one of the type figures of *Vibracellina caribbea* Osburn (1947, pl. 1, fig. 2), which is here reproduced in amended form (Fig. 2). As seen in this figure, the ancestrula sometimes gives off two vibracula, each of which marks the beginning of a spiral. In adult colonies, which sometimes completely envelop their supporting object, the bispiral arrangement is usually obscured as the zoarium adapts itself to the shape of its substratum by repeated branching of the spirals.

It is interesting to observe that the rotational direction of the spirals is rigorously

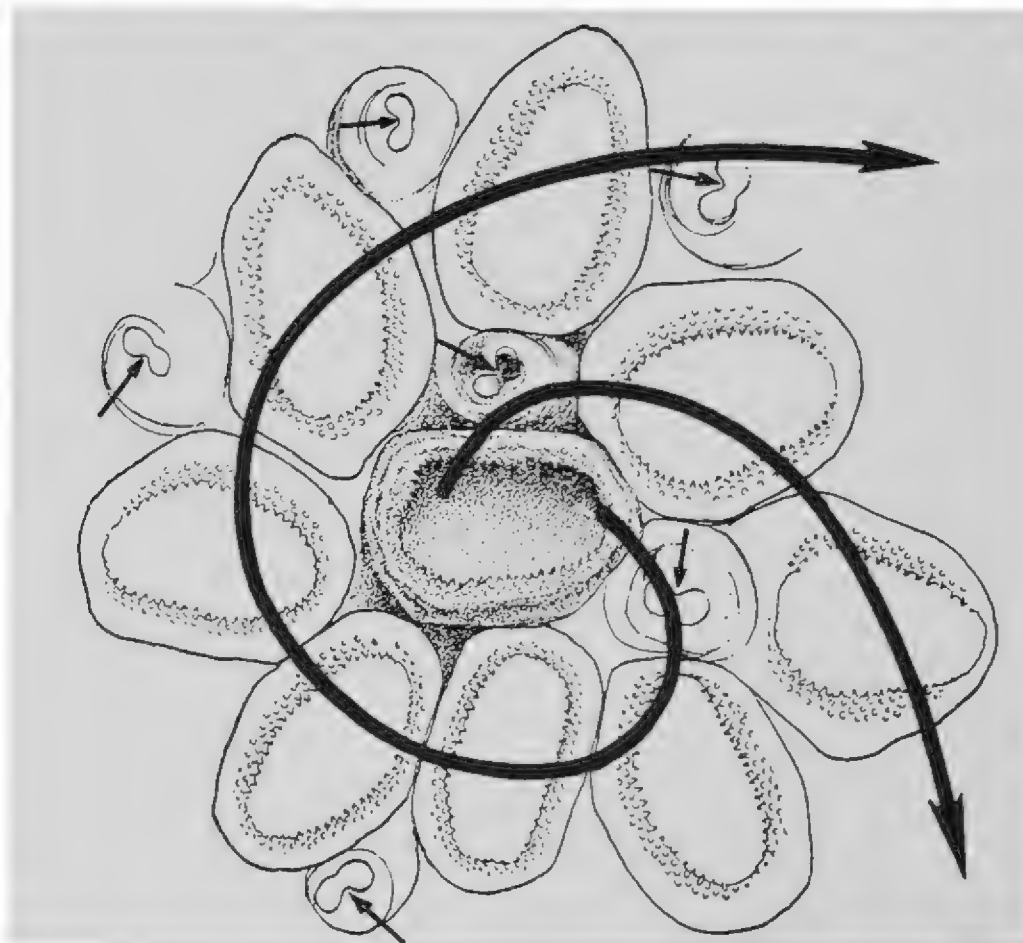


FIG. 2. *Setosellina goësi* (Silén). Ancestrular region of a right rotational specimen. This is the original type figure of *Vibracellina caribbea* Osburn, with arrows added. The large arrows follow the concentric spiral arrangement of the zooecia. The small arrows indicate the largest of the two vibracular teeth.

reflected in 1) the orientation of the larger vibracular tooth, and therefore of the vibracular seta, as indicated by the small arrows in Fig. 2, and in 2) the position of the vibracula with respect to the median line of the parent zooecia. Thus it remains possible to distinguish a left from a right rotational specimen, in which the original bispiral arrangement has become obscured, from the orientation and position of the vibracula. A small septular pore is always present in the angles between the vibraculum and the adjacent zooecia on either side at the growing edge of the zoarium.

In *Setosellina roulei* Calvet (1906, p. 157; 1907, p. 395, pl. 26, figs. 5, 6) the type species of *Setosellina* Calvet, 1906, from the Cape Verde Islands, and in *Setosellina constricta* Harmer (1926, p. 264, pl. 16, fig. 1) from the Malay Archipelago, the vibracula do not occur distinctly outside the median line of the parent zooecia.

Osburn (1947), when introducing *Vibracellina caribbea* from the southern part of the Caribbean, was evidently unaware of Silén's earlier paper, published in war-time Europe, in which the same form was described as *Heliodoma goësi* from the West Indies. Both authors have independently considered the possibility of the Recent West Indian-Caribbean species being identical with *Vibracellina laxibasis* Canu and Bassler (1928, p. 23, pl. 32, fig. 2), from the Pliocene of Bocas Island, Almirante Bay, Panama. Examination of the syntypes of *Vibracellina laxibasis* (U.S.N.M. Cat. No. 70868, 9 specimens) in the U.S. National Museum reveals, better than the type figure, that the orientation of the vibracula is by no means as regular as is the case in *Setosellina goësi*.

Setosellina goësi is clearly more at home in the Eastern Gulf and in the Straits of Florida than it is in the North-western Gulf of Mexico, and this may be a matter of outspoken preference for a carbonate sand bottom. Although occasionally found encrusting coarse quartz grains, its usual small support is calcareous: altered (black) carbonate particles, fragments of calcareous algae and of molluscs, echinoid spines, and sometimes the tests of the Foraminifera *Amphistegina gibbosa* d'Orbigny and *Globorotalia menardii* (d'Orbigny). The discriminating power of the larva in seldom selecting its supporting object too large is indeed remarkable. Six of the seven occurrences in the North-western Gulf are located in the direct vicinity of topographic highs (banks) near the edge of the continental shelf with their apron of carbonate detritus.

Occurrence

North-western Gulf: seven stations, mostly located in the direct vicinity of topographic highs (banks)	12 $\frac{1}{3}$ –70 fathoms
Eastern Gulf and Florida Straits: numerous stations	8 $\frac{2}{3}$ –196 fathoms

Additional occurrence

Caroline 1933 Station 10, near San Juan, Puerto Rico, 100 fathoms. 3 specimens.

Distribution

Virgin Islands	300–480 metres
Anguilla	200–375 metres
Cape la Vela, Colombia	10 fathoms
Gulf of Venezuela	19–41 fathoms
Aruba	
Tortugas	
Margarita	

Family CALLOPORIDAE NORMAN, 1903

Genus *Retevirgula* Brown, 1948

Retevirgula tubulata (Hastings)

(Pl. I, figs. 4-6)

Hincksina periporosa Canu and Bassler (1928a, p. 22, *partim*, pl. 2, fig. 11, *non* figs. 8-10 = *Retevirgula periporosa* Canu and Bassler sp.), ?Osburn (1940, p. 356, pl. 2, figs. 18, 19).

Pyrulella tubulata Hastings (1930, p. 709, pl. 6, figs. 20-26), Osburn (1947, p. 14).

Retevirgula tubulata Osburn (1950, p. 86, pl. 8, fig. 1), Soule (1959, p. 17).

Material

Locality 99(1), 150(1), 179(27), 180(1), 379(1), 382(2), 383(3), 386(2), 387(3), 388(2), 443(2), 444(1), 464(1).

Remarks

I have examined most of the material listed under the original description of *Hincksina periporosa* Canu and Bassler (1928a, p. 23) which is kept in the U.S. National Museum in Washington, D.C. Only the specimen(s) from Albatross Station D.2167, off Habana, Cuba, 201 fathoms, was not found. It appears that there are two (and possibly three) species involved.¹ The greater part of this material, *i.e.* the specimens from the Gulf of Mexico (Albatross Station D.2405), the Straits of Florida (Albatross Station D.2639, including two exchange specimens now in the British Museum (N.H.), 32.3.7.31) and an additional Western Atlantic sample (Albatross Station D.2612, E of Wilmington, N.C., 52 fathoms) was found to belong to *R. tubulata*. Only the two Cuban specimens from Albatross Station D.2319, marked "Cotypes" (U.S.N.M. Cat. No. 7519), on which the type figures 8-10 were based, represent genuine *R. periporosa*. In order to make the position quite definite, one of the two Cuban "Cotypes," which has been circled in red on the actual specimen and which has been figured by Canu and Bassler in pl. 2, fig. 10 of their Gulf of Mexico paper (1928a) with part of its spines still intact, is hereby chosen as the lectotype of *Hincksina periporosa*.

As established on the Cuban specimens, the ovicells of *R. periporosa* are small, hyperstomial and reduced rather than entozoecial (as implied in Canu and Bassler's reference of this species to *Hincksina*; cf. Marcus, 1949, p. 7), with a fair-sized circular foramen facing entirely distally. In some cases the proximal lip of the ovicell has grown out vertically into a conspicuous triangular hood.

The ovicells of *R. tubulata*, on the other hand, have been described and figured by Hastings (1930). They are large, hyperstomial and the large circular foramen occupies a frontal position. The proximal lip is only very slightly out-turned.

Another difference is found in the arrangement of the spines. As far as I have been able to make out on the lectotype specimen of *R. periporosa* in which part of the spines are still preserved, there is no such differentiation in the orientation of the spines which

¹ Two of the three specimens from Albatross Station D.2405, Gulf of Mexico, 30 fathoms (U.S.N.M. Cat. No. 7520) do not seem to belong either to *Retevirgula periporosa* or to *R. tubulata*; the third specimen, marked "Cotype," belongs to *R. tubulata* and was used for pl. 2, fig. 11 of the Gulf of Mexico Memoir (Canu and Bassler, 1928a). The explanation of pl. 2 is, therefore, inaccurate. The following corrections should be made: pl. 2, figs. 8, 9, 10 refer to specimens (of *Retevirgula periporosa*) from Albatross Station D.2319, north of Cuba, 143 fathoms (U.S.N.M. Cat. No. 7519); pl. 2, fig. 11 refers to a specimen (of *R. tubulata*) from Albatross Station D.2405, Gulf of Mexico, 30 fathoms (U.S.N.M. Cat. No. 7520).

surround the opesia as there is in *R. tubulata* (cf. Hastings, 1930, p. 710). They are all erect and only slightly curved inward over the opesia.

Whether Osburn's (1940) shallow water form taken at 20 fathoms off Guanipa Harbor, Cuba and at 2 fathoms in Bermuda was correctly identified as *R. periporosa*, or whether it also belongs to *R. tubulata*, cannot be ascertained at present. In view of the shallow depth the latter possibility seems more likely.

Occurrence

North-western Gulf: Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 278	38 fathoms
Cavalier 1956 Station 227	37½ fathoms
Cavalier 1956 Station 228	27½ fathoms
Eastern Gulf: Atlantis 1951 Stations 154, 157-158, 161-163	20-64 fathoms
Vema-3 1954 Dredge #2	29 fathoms
SSW of John's Pass, Florida	34 fathoms
Florida Straits: E of Triumph Reef	45 fathoms

Additional occurrence

Albatross Station D.2612, E of Wilmington, N.C. (U.S.N.M.)	52 fathoms
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Distribution

Gulf of Mexico	30 fathoms
Florida Straits	56 fathoms
?Puerto Rico	20 fathoms
?Bermuda	2 fathoms
Aruba	23 fathoms
Galapagos	4, 12 fathoms
Gorgona, Columbia	30 fathoms
American Pacific coast from Angel de la Guardia Island, Gulf of California to Gorgona, Columbia	shallow water to 80 fathoms

Genus *Parellisina* Osburn, 1940

Parellisina latirostris Osburn

(Pl. VIII, fig. 3)

Parellisina latirostris Osburn (1940, p. 361, pl. 4, figs. 33, 34), Osburn (1949, p. 5, fig. 4).

Material

Locality 68(1), 69 (7 fragments, probably all part of one large specimen, originally incrusting a smooth, rounded, fist-size cobble. 88(6), 94(1), 386(2), 387(2), 388(2).

Remarks

The characteristic avicularium and corresponding distal kenozoecium have only been found in a specimen from Locality 69 and from Locality 88, located at Stetson Bank and Claypile Bank respectively. Of the remaining specimens and fragments the identification must necessarily remain somewhat uncertain.

Occurrence

North-western Gulf: Stetson Bank area	approx. 30 fathoms
Cavalier 1956 Station 322	23 fathoms
Cavalier 1956 Station 316	50 fathoms
Eastern Gulf: Atlantis 1951 Stations 161–163	20–22 fathoms

Distribution

Puerto Rico	7–27 fathoms
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Family CHAPERIIDAE JULLIEN, 1888

Genus *Chaperia* Strand, 1928

Chaperia patula (Hincks)

(Pl. II, fig. 2)

Membranipora patula Hincks (1881a, p. 150, pl. 9, fig. 4), Hincks (1882, p. 465), Robertson (1908, p. 263), O'Donoghue and O'Donoghue (1923, p. 25).

Chaperia galeata (Busk) Canu and Bassler (1923, p. 52, *partim*, pl. 34, figs. 9, 10, *non* fig. 8 = *Chaperia californica* Osburn), Canu and Bassler (1928a, p. 155), Maturo (1957, p. 39, text-fig. 33).

Chapperia patula Osburn (1950, p. 89, pl. 10, figs. 1, 2), Soule and Duff (1957, p. 96, *cum syn.*), Soule (1959, p. 20).

Material

Locality 2(2), 93(1), 94(4), 95(5), 99(12), 102(12), 150(1), 179(1), 181(7), 193(1), 332(1), 378(5), 379(1), 380(1), 383(4), 384(10), 411(1), 412(5), 443(2).

Remarks

Our fragmentary specimens are perfectly identical in their zooecial characters with the specimen from Albatross Station D.2405, Gulf of Mexico, 30 fathoms (U.S.N.M. Cat. No. 7475, identified by Canu and Bassler (1928a, p. 155) as *Chaperia galeata* (Busk), and with two other specimens from the same locality simply labelled "*Chaperia*," in the U.S. National Museum. The much larger Albatross specimens are all erect and dichotomously branching. Our figured specimen (Pl. II, fig. 2) is incrusting.

The only reference which Canu and Bassler gave in 1928 was to *Chaperia galeata* (Busk) Canu and Bassler (1923, p. 52), *i.e.* to fossil material now split up between *C. patula* (Hincks) and *C. californica* (Osburn)—see Osburn, 1950, p. 89, 91.

No doubt the Recent *Chaperia* from the Gulf of Mexico belongs to *C. patula* (Hincks). Our specimens have the large dimensions and the shelf-like extension of the occlusor-laminae inside the opesia described by Osburn (1950, p. 90). The occlusor-laminae end proximally in a pair of raised, rounded knobs, a condition strikingly similar to that found in the Upper Cretaceous genus *Hagenowinella* Canu, 1900. There are usually four, sometimes six, distal spine-bases, arranged in pairs on either side of the small triangular avicularium. This avicularium is lacking on ovicelled zooecia.

One of the Albatross specimens has the opercula, the ectocyst and part of the spines still preserved. This specimen is pink coloured with brownish opercula and spine-bases. The spines are long and tapering, hollow and simple, not bifurcate or cervicorn.

The identification was checked by comparison with a specimen of *C. patula* from the

Queen Charlotte Islands, 86.3.6.23, Hincks Collection, in the British Museum (Natural History).

Another species of *Chaperia*, with some reserve referred to *C. cervicornis* (Busk), has been recorded from the Caribbean (Osburn, 1947, p. 15). According to Osburn this form has branched spines.

Occurrence

North-western Gulf: off Rio Grande	50 fathoms
Cavalier 1956 Station 317	50 fathoms
Cavalier 1956 Station 316	50 fathoms
Cavalier 1956 Station 315	92 fathoms
Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 308	40 fathoms
Cavalier 1956 Station 278	38 fathoms
Cavalier 1956 Station 227	37½ fathoms
Cavalier 1956 Station 229	57 fathoms
Cavalier 1956 Station 176	100 fathoms
Eastern Gulf: Sandpile Bank	49 fathoms
Atlantis 1951 Stations 153–155, 158–159	28–80 fathoms
Vema-3 1954 Dredge #1, #2, BT #2	29–117 fathoms

Additional occurrence

2 incrusting specimens, labelled "*Chaperia galeata* Busk" (U.S.N.M. Cat. No. 9769), from Sta. 104, near San Juan, Puerto Rico, 50 fathoms. Presumably this is Caroline 1933 Station 104, from 80–120 fathoms; see Bartsch, 1933, p. 29.

Distribution

Beaufort, North Carolina	
Gulf of Mexico	30 fathoms
American Pacific coast from British Columbia to Lower California	0–47 fathoms
Gulf of California	10–50 fathoms

Fossil distribution

Pleistocene of Santa Monica and Santa Barbara, California.

Family ONYCHOCELLIDAE JULLIEN, 1882

Genus *Floridina* Jullien, 1882

Floridina parvicella Canu and Bassler
(Pl. II, fig. 5)

Floridina parvicella Canu and Bassler (1923, p. 57, pl. 31, fig. 12).

Material

Locality 76(3), 179(1), 354(3), 357(2), 358(1), 359(1), 360(10), 361(1), 363(1), 365(7), 379(1), 388(1).

Remarks

Floridina parvicella rather closely resembles the type species, *Floridina antiqua*

(Smitt). It differs, however, in its smaller dimensions and in the rounded tubercles which are constantly found at the junction of three zooecia. I doubt whether Canu and Bassler have observed tubercles in their Pliocene fossil, as no mention of these structures is made in the text. Their presence is suggested in the photograph of the type specimen. Dr. Richard S. Boardman, of the U.S. National Museum, has greatly obliged me by comparing our figured specimen from Heald Bank with the type specimen (U.S.N.M. Cat. No. 68477). Dr. Boardman states (*in litt.*): "your specimen of *Floridina* from Heald Bank appears . . . to be identical with *F. parvicella*. I checked against the holotype and the tubercles are equally developed. Also, this transparent, more massive deposit is extended along the boundaries between zooecia in several places in both colonies. I saw nothing to differentiate the two colonies into separate species." Avicularia are present in the figured specimen from Heald Bank. They are similar to those found in *F. antiqua*, but smaller.

Hitherto only known as a Pliocene fossil from the U.S. Atlantic coastal plain, this species is surprisingly found living in the Gulf of Mexico today.

Occurrence

North-western Gulf: Heald Bank Dredge sample	81 $\frac{1}{3}$ fathoms
Cavalier 1956 Station 227	371 $\frac{1}{2}$ fathoms
Eastern Gulf: off Choctawhatchee Bay	121 $\frac{1}{2}$ fathoms
off Panama City	11–16 fathoms
off Cedar Keys	20, 64 fathoms

Fossil distribution

Pliocene (Waccamaw Marl) Waccamaw River, Horry County, South Carolina.

Family MICROPORIDAE GRAY, 1848

Genus *Monoporella* Hincks, 1881

Monoporella divae Marcus

(Pl. II, figs. 3–4)

Monoporella divae Marcus (1953, p. 286, pl. 2, figs. 26–27; pl. 3, fig. 28).

Material

Locality 179(5).

Occurrence

North-western Gulf: Cavalier 1956 Station 227	371 $\frac{1}{2}$ fathoms
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Distribution

Espírito Santo, Brazil	35 meters
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Family SETOSELLIDAE LEVINSSEN, 1909

Genus *Setosella* Hincks, 1877

Setosella vulnerata (Busk)

(Pl. II, fig. 7)

Membranipora vulnerata Busk (1860a, p. 124, pl. 25, fig. 3).

Setosella vulnerata Hincks (1877, p. 529), Hincks (1880a, p. 181, pl. 21, fig. 7), Hincks (1880b, p. 73, pl. 9, fig. 5), Jullien (1883, p. 524, pl. 17, fig. 66), Calvet (1907, p.

394), Levinsen (1909, p. 196), Waters (1925 p. 349, pl. 21, fig. 2), Marcus (1940, p. 155, text-fig. 83), Silén (1942, p. text-fig. 4, pl. 2, figs. 8–9).

Material

Locality 411(1), 458(2), 458a(1).

Remarks

Setosella vulnerata (Busk) is one of the few species of Bryozoa which has been recorded from a depth greater than 3000 metres (Silén, 1951, p. 68).

Occurrence

Eastern Gulf: Vema-3 1954 Dredge #1	117 fathoms
Florida Straits: off Mollasses Reef Light	120–122 fathoms

Distribution

Shetland Islands	80–110 fathoms
Bergen, Norway	
Skager Rack	200 metres
Bay of Biscay	392, 1068, 1094 metres
Portugal	
Mediterranean: off Marseilles, Nice, Capri, Algeria and Tunis	
Azores	
Josephine Bank, Atlantic	500–650 metres
NW of Morocco	636 metres
Funchal Bay, Madeira	30 fathoms
Canary Islands	3700 metres
Cape Verde Islands	460 metres
N of Anguila, West Indies	170 fathoms
Saint Barthélemy, West Indies	30–45 metres
Gulf of Aden	30 metres

Family CELLARIIDAE HINCKS, 1880

Genus *Euginoma* Jullien, 1883

Euginoma cavalieri sp. nov.
(Pl. II, fig. 6)

Holotype

Locality 97: Cavalier 1956 Station 313. U.S.N.M. 648022.

Paratypes

Locality 349: Albatros 1885 Station D.2383. 7 specimens. U.S.N.M. 648023.

Diagnosis

Euginoma with the internodes consisting of $3n$ or $3n + 1$ zooecia, with n varying between 2 and 6. Single median zooecia alternate with paired lateral zooecia, imparting a peculiar nodose aspect to each internode.

Description

Zoarium articulated. Internodes straight, each consisting of $3n$ or $3n + 1$ zooecia,

with n varying between 2 and 6; reaching a maximum length of 4 mm. *Zooecia* opening on the frontal side of the zoarium only; distinctly defined by thin raised margins; arranged in three longitudinal rows in alternating fashion. The zooecia which occupy the median row are single, those which make up the two lateral rows are paired. This arrangement results in a distinct bilateral symmetry and, simultaneously, in the nodose aspect of each internode. *Opesia* relatively large, semicircular, the proximal lip straight. Cryptocyst well-developed, finely granular, developed into a pronounced cryptocyst-ridge in the form of an oval horseshoe around the opesia with the two legs converging proximally. A large raised pore, facing proximally, is occasionally found at the base of the single median zooecium at the proximal end of an internode. Presumably this pore, and the small inflated chamber into which it leads, lodged the base of an anchoring filament or rootlet. *Avicularia* not observed. *Ovicells* entotoichal, opening through an independent transverse crescentic slit distally to the opesia. The few fertile zooecia observed all form part of the lateral rows. Dorsal side of internodes convex, finely granular, with thin raised sutures delineating the zooecial boundaries and with a small ringed median pore in the distal part of each single median zooecium.

Measurements

Holotype
 $L_z = 0.45$ mm
 $l_z = 0.20$ mm
 $h_o = 0.10$ mm
 $l_o = 0.09$ mm

Remarks

According to Harmer (1926, p. 328) the genus *Euginoma* Jullien, 1883 is referable to the Aspidostomatidae, but I think it definitely belongs in the Cellariidae, as already implied by Jullien (1883, p. 520). The type species, *Euginoma vermiformis* Jullien is a deep water form from the Eastern Atlantic (Bay of Biscay; Canary Islands) with an established bathymetric range of 1094–3700 m.

Euginoma cavalieri sp. nov. has the following features in common with the type species: 1) the shape and location of the opesia; 2) the development of a cryptocyst-ridge around the opesia; 3) the location and character of the ovicell; 4) the absence of avicularia; 5) the finely granular aspect of the entire zoarium. It is also a deep water form (200–1181 fathoms). It differs from the type species in the peculiar arrangement of the zooecia, and in the relative size of the opesia.

Occurrence

North-western Gulf: Cavalier 1956 Station 313	200 fathoms
Eastern Gulf: Albatross 1885 Station D.2383	1181 fathoms

Family BICELLARIELLIDAE LEVINSEN, 1909

Genus *Beania* Johnston, 1840

Beania hirtissima (Heller)

(Pl. VIII, fig. 4)

Diachoris hirtissima Heller (1867, p. 94, pl. 1, figs. 6–7).

Beania hirtissima Waters (1918, p. 8, pl. 1, fig. 2, *cum syn.*), Marcus (1937, p. 62, pl. 14,

fig. 31), Osburn (1940, p. 397), Osburn (1950, p. 172, pl. 26, figs. 4–5), Gautier (1955, p. 243), Gautier (1957b, p. 103).

Material

Locality 444(2).

Remarks

Waters (1897, p. 17; 1918, p. 8) and Osburn (1950, p. 172) have indicated the number and arrangement of the distal and lateral spines. In this respect our two specimens compare very well with Mediterranean material of *B. hirtissima* in my possession, although on the whole their spines are more delicate and less differentiated as to size.

Occurrence

Eastern Gulf: SSW of John's Pass, Florida 34 fathoms

Distribution

Adriatic	
Mediterranean	
Madeira	"on weeds between tide-marks"
Cape Verde Islands	10 fathoms
Bermuda	
Guanica Harbor, Puerto Rico	
Bay of Santos, Brazil	20 metres
Port Culebra, Costa Rica	17 fathoms
Secas Islands, Panama	25 fathoms

Family SCRUPOCELLARIIDAE LEVINSEN, 1909

Genus *Scrupocellaria* Van Beneden, 1845

Scrupocellaria harmeri Osburn

(Pl. III, figs. 1–2)

Scrupocellaria harmeri Osburn (1947, p. 20, pl. 3, figs. 1, 2), Osburn (1950, p. 138, pl. 18, figs. 9, 10; pl. 20, fig. 4).

Material

Locality 444(17).

Remarks

Among the species of *Scrupocellaria* with paired axillary vibracula and small, distally truncated scutum, *S. harmeri* resembles *S. scupea* Busk, but is a more delicate and slender species. Moreover, the opesia occupies less than half the frontal length of the zooecia in *S. harmeri*, whereas the reverse is true in *S. scupea*.

Occurrence

Eastern Gulf: SSW of John's Pass, Florida 34 fathoms

Distribution

Aruba	23–24 fathoms
Galapagos	32 fathoms
Santa Catalina Island, California	2–3 fathoms
La Jolla, California	"among algae"

Genus *Caberea* Lamouroux, 1816

Caberea boryi (Audouin)

(Pl. III, figs. 3–4)

Crisia boryi Audouin (1826, p. 242), Savigny (pl. 12, fig. 4).

Caberea boryi Harmer (1926, p. 362, pl. 24, figs. 13–15), Marcus (1941a, p. 46, pl. 1, figs. 3A–B), Hastings (1943, p. 367, text-figs. 19A–B, *cum syn.*), Osburn (1950, p. 129, pl. 15, figs. 4–6).

Material

Locality 88(10), 99(9), 101(1), 444(3).

Remarks

The tapering distal lobe of the scutum is fused to a complete calcareous bar which spans the opesia below the orifice. According to Hastings (1943, p. 365), this condition is typical for representatives of the *Caberea boryi* group. The rounded proximal lobe of the scutum, practically flush with the opesial border, completely fills the opesia with the exception of a narrow crescentic slit.

Osburn (1950, p. 129) definitely observed the bar in Californian specimens, believing it to be part of the scutum. His figures (*l.c.*, pl. 15, figs. 4, 6), however, are obviously incomplete in as much as the artist has left out the structure altogether.

Occurrence

North-western Gulf: Cavalier 1956 Station 322	23 fathoms
Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 309	57 fathoms
Eastern Gulf: SSW of John's Pass, Florida	34 fathoms

American distribution

Bay of Santos, Brazil	
Anacapa Passage, Southern California	15–50 fathoms
Cedros Island, Lower California	10–15 fathoms
Guadalupe Island, Lower California	17 fathoms
Gulf of California	

Family CRIBRILINIDAE HINCKS, 1879

Genus *Figularia* Jullien, 1886

Figularia contraria sp. nov.

(Pl. IV, fig. 1; Pl. VIII, fig. 5)

Holotype

Locality 69. USNM 648027. 70 mi. SE of Freeport, Texas. Approximately 30 fathoms. 1 specimen (and 2 fragments) originally encrusting a smooth, rounded, fist-size cobble. This distance and direction locate the sample in the immediate vicinity of Stetson Bank (Lat. 28°9'48" N, Long. 94°17'42" W), which is well compatible with the presence of a cobble. Stetson Bank owes its presence to an underlying salt diapir which has caused older, indurated sedimentary rocks to crop out on the Gulf bottom at this locality. Pebbles and rock fragments dredged from Stetson Bank have been described by Ewing and Ericson (1954) and by Neumann (1958).

Diagnosis

Figularia with the frontal shield of the fertile zooecia consisting of 5–7, that of the sterile zooecia consisting of 8–11 (mostly 9) costae. Orifice distinctly smaller in the ovicelled zooecia.

Description

Zoarium encrusting. *Zooecia* irregularly hexagonal, strongly variable in size and shape, distinctly defined by shallow grooves. *Gymnocyst* forming a continuous zone of variable width between the zooecial margins and the frontal shield, and bearing a number of concentric growth-striae which are particularly well apparent proximally. *Frontal shield* of variable size, slightly raised above the level of the gymnocyst, consisting of 5–7 costae in the ovicelled zooecia and of 8–11 (mostly 9) costae in the sterile zooecia. The costae are fused in the median line and the distal pair forms the apertural bar. The intercostal space is subdivided by secondary fusion. The resulting six rounded lacunae between adjacent pairs of costae decrease in size towards the centre of the frontal shield, and the two smallest, central lacunae often coalesce to form one single, larger pore. A small, slightly raised, pelma is found at the lateral end of each costa. *Orifice* with a broad shallow sinus and a pair of minute lateral condyles; distinctly smaller in the ovicelled zooecia. *Avicularia* not observed, presumably rare. *Ovicells* large, galeate, occupying almost the entire distal half of the fertile zooecia, with a distinct median frontal carina. The ovicells are perforated and the following arrangement of pores (fenestrae) seems to prevail: 1) a pair of small frontal fenestrae directly adjacent to the carina; 2) a pair of slightly larger, lateral fenestrae at the same height; 3) a median group of several pores on the distal slope. This arrangement is not clearly brought out in the figure. (Pl. IV, fig. 1).

Measurements

	sterile	fertile
Lz	= 0.57–0.87 mm	= 0.55–0.72 mm
lz	= 0.32–0.45 mm	= 0.30–0.40 mm
ha	= 0.15 mm	= 0.07–0.09 mm
la	= 0.15 mm	= 0.12–0.14 mm

Remarks

None of the four Recent American species of *Figularia* described to date, *F. magellanica* (Calvet), *F. patagonica* (Waters), both from the Magellan region, *F. ampla* (Canu and Bassler), from Havana, Cuba and *F. hilli* (Osburn), from California, is directly comparable with the present species. The striking feature in this species is that, contrary to what is normally seen in *Figularia*, the orifices of the ovicelled zooecia are smaller than those of the sterile zooecia.

Occurrence

North-western Gulf: Stetson Bank area

approx. 30 fathoms

Bellulopora gen. nov.

Colletosia (partim) Osburn (1950, non *Colletosia* Jullien, 1886 = *Umbonula* Hincks, 1880).

Type species

Colletosia bellula Osburn, 1950, p. 188, pl. 29, fig. 1. Recent: Galapagos Islands and Gulf of California; Pleistocene: Newport Harbor Mesa, Southern California.

Diagnosis

Incrusting Cribrimorph with a keyhole-shaped (cleithridiate) orifice, flanked by a pair of small, adventitious, pedicellate avicularia. Ovicell hyperstomial, the ectoecium consisting of radiating costate, separated by rows of lacunae.

Remarks

The necessity of introducing a new genus is explained under *B. bellula* (see below).

Bellulopora bellula (Osburn)

(Pl. IV, fig. 2)

Colletosia bellula Osburn (1950, p. 188, pl. 29, fig. 1), Soule (1959, p. 49).

Material

Locality 179(1), 383(1).

Remarks

Osborn (1950, p. 189) referred this form to Jullien's genus *Colletosia* because he considered it to be congeneric with *Collestosia radiata* (Moll).

Recently, Bobies (1956, p. 244) has shown that *Colletosia* Jullien, 1886 is not a Cribrimorph genus at all, but a synonym of the Ascophoran genus *Umbonula* Hincks, 1880. See also Brown, 1958, p. 54.

Eschara radiata Moll is the genoelectotype (selected by Canu and Bassler, 1929, p. 33) of *Cribrilaria* Canu and Bassler, 1928. This well-known species has a small, semicircular orifice and relatively large, lanceolate, vicarious avicularia, which occur scattered throughout the zoarium or may be absent altogether. It is difficult to see how this species could possibly be congeneric with "*Colletosia*" *bellula*.

"*Colletosia*" *bellula* Osburn has a keyhole-shaped (cleithridiate) orifice, flanked by a pair of small, adventitious, pedicellate avicularia, which are very constant in their presence. This condition is unique among the known Recent Cribrimorphs and necessitates the introduction of a new genus, for which the name *Bellulopora* is proposed.

The cleithridiate orifice with a small avicularium on either side is reminiscent of conditions obtaining in certain extinct Cribrimorph genera, e.g. *Pliophloea* Gabb and Horn, 1862 (Upper Cretaceous—Paleocene). The avicularia in *Pliophloea*, however, are vicarious, not adventitious, and the ovicell is distinctly carinate, not costate.

Occurrence

North-western Gulf: Cavalier 1956 Station 227	37½ fathoms
Eastern Gulf: Atlantis 1951 Station 158	33 fathoms

Distribution

Galapagos Islands	50–60 fathoms
Gulf of California	14–40 fathoms

Fossil distribution

Pleistocene of Newport Harbor Mesa, Southern California.

Family CHORIZOPORIDAE HARMER, 1957

Genus *Chorizopora* Hincks, 1879

Chorizopora brongniartii (Audouin)

(Pl. IV, fig. 5)

Flustra brongniartii Audouin (1826, p. 240), Savigny (pl. 10, fig. 6).*Chorizopora brongniarti* Canu and Bassler (1930, p. 14), Osburn (1952, p. 279), Harmer (1957, p. 948, text-fig. 99, pl. 73, figs. 19, 20, *cum syn.*).*Material*

Locality 395(1).

Remarks

There is only one previous record of this species from the Americas, referring to a single colony from the Galapagos Islands.

Occurrence

Eastern Gulf: Atlantis 1951 Station 170 11 fathoms

American distribution

Galapagos Islands 40 fathoms

Family HIPPOPODINIDAE LEVINSEN, 1909

Genus *Hippopodina* Levinsen, 1909*Hippopodina bernardi* sp. nov.

(Pl. IV, figs. 3-4)

Holotype

Locality 99 (fragment the size of one zooecium). U.S.N.M. 648030.

Paratypes

Locality 99(6). U.S.N.M. 648031 (figured), 648032.

Other material

Locality 94(3).

Diagnosis

Hippopodina with one long, acuminate, proximally directed frontal avicularium and with two rows of marginal pores around a large, granular, imperforate pectoral area.

Description

Zoarium encrusting. *Zooecia* moderately large, distinctly defined by a slightly raised margin flanked on either side by rows of marginal pores. *Orifice* subcircular, divided by a pair of minute lateral condyles in a large porta and a wide and shallow concave vanna. *Peristome* only laterally raised, slightly cusped distally on either side. *Frontal wall* broadly convex, with a large, granular, imperforate pectoral area, surrounded by two rows of marginal pores. *Avicularia* single, proximally to the orifice, the long acuminate rostrum proximally directed, cutting obliquely across the pectoral area. *Ovicells* large, hyperstomial, flattened in front, finely and evenly perforate.

Measurements

Holotype
 Lz = 0.87 mm
 lz = 0.62 mm
 ho = 0.19 mm
 lo = 0.18 mm

Remarks

Hippopodina pectoralis Harmer (1957, p. 976, pl. 67, figs. 6, 10, 11), a related deep water species from the Celebes Sea, is slightly larger and has three rows of marginal pores and no avicularia.

Another allied species appears to have been figured as *Codonellina cribriformis* (O'Donoghue and O'Donoghue) by Osborn (1952, pl. 46, fig. 16). There is a remarkable discrepancy between this figure and the corresponding text. Whereas Osburn's text matches and supplements O'Donoghue's description and figure (1923, p. 42, pl. 4, fig. 30), the figured specimen differs in having an imperforate pectoral area, a double row of marginal pores and a small lateral avicularium near the proximal border of the orifice with the rostrum proximally directed.

Hippopodina bernardi sp. nov. is named after Dr. H. A. Bernard, who conceived and organized the Cavalier 1956 campaign.

Occurrence

North-western Gulf: Cavalier 1956 Station 316	50 fathoms
Cavalier 1956 Station 311	

Family SCHIZOPORELLIDAE JULLIEN, 1883

Genus *Arthropoma* Levinsen, 1909

Arthropoma cecilii (Audouin)
 (Pl. IV, fig. 6)

Flustra cecilii Audouin (1826, p. 239), Savigny (pl. 8, fig. 3).

Arthropoma cecilii Marcus (1937, p. 93, pl. 18, fig. 49), Osburn (1952, p. 333, pl. 38, figs. 1-3), Marcus (1953, p. 297), Harmer (1957, p. 1001, text-fig. 108, pl. 72, fig. 23, *cum syn.*), Soule and Duff (1957, p. 108).

Material

Locality 99(6), 102(1), 386(2).

Remarks

Marcus (1937, p. 93) includes *Arthropoma cornuta* Canu and Bassler (1923, p. 97, pl. 16, fig. 3) from the Miocene Choctawhatchee marl of Florida in the synonymy of this species.

Occurrence

North-western Gulf: Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 308	40 fathoms
Eastern Gulf: Atlantis 1951 Station 161	22 fathoms

American distribution

Pacific coast of America between the Queen Charlotte Islands
and Chatham Bay, Cocos Island, Costa Rica

Galapagos Island

33½ fathoms

Bay of Santos, Brazil

11 fathoms

Espírito Santo, S of Vitória, Brazil

35 metres

American fossil distribution

Miocene (Choctawhatchee marl) of Florida

Pleistocene of San Pedro, Southern California.

Genus *Cribellopora* Gautier, 1957

Cribellopora trichotoma (Waters)

(Pl. IV, figs. 7–8)

Hippothoa isabelleana (d'Orbigny) Smitt (1873, p. 44, *partim*, pl. 8, fig. 168, *non* figs. 166, 167).

?*Cribellopora simplex* Gautier (1957a, p. 211, text-figs. 1, 2).

Schizoporella trichotoma Waters (1918, p. 19, pl. 2, figs. 1–4), Hastings (1930, p. 720, pl. 11, figs. 58, 59), Osburn (1952, p. 318, pl. 37, fig. 3), Soule (1961, p. 10).

Material

Locality 2(2), 94(5), 99(2), 179(1), 379(9).

Remarks

It is highly probable that this is the form from 42 fathoms, identified by Smitt (1873, p. 44, pl. 8, fig. 168) as a variety of *Hippothoa isabelleana* with the following description: "The first variety (fig. 168) was growing in one single layer of whitish and yellowish hue on *Oculina* and *Nullipora*, at the depth of 42 fathoms. It is in a pretty hard degree of calcification; thus the pores on the convex frontside of the zooecia, and still more on the rounded, inflate ooecia, sometimes scarcely are discernible. The zooecial aperture, with a breadth of about 0.14 mm, secondarily raised into a moderately high rim, is of a semielliptical or semicircular form, with a semicircular sinus in the middle of the straight proximal margin. The avicularia are wanting."

It is with some reserve that the Gulf specimens are referred to *C. trichotoma*. The stellate pores appear to be less evenly and less densely spaced than on Waters's syntypes from St. Vincent Harbour, Cape Verde Islands, 10 fathoms, 26.10.1.17, or on those from the Galapagos Islands, 10–12 fathoms, 29.4.26.251, and they are definitely less conspicuous (cf. Smitt's description). The zoarial wall is very thin and often almost transparent, which explains their fragmentary state. In these characters they more closely resemble the two specimens from John Adams' Bank, Brazil 99.7.1.2236, 2237, Busk Collection. Harmer (1900, p. 254) has elucidated the geographical position of this locality.

Dr. Hastings has kindly drawn my attention to a recent paper by Gautier (1957a), in which a strikingly similar, if not identical, species is described and figured as *Cribellopora simplex* nov. gen. nov. spec. from the Balears. The only noticeable difference is perhaps found in the nature of the frontal structure on the ovicell, which Waters described as "a median ridge and a mucro, with ridges from the mucro to the distal end of

the aperture," whereas Gautier observed "une tubérosité calcaire lisse." Gautier's species is therefore tentatively included in the above synonymy, but his new genus is here readily adopted as it would seem to fit certain Schizoporellidae with stellate frontal pores.

Occurrence

North-western Gulf: off Rio Grande	50 fathoms
Cavalier 1956 Station 316	50 fathoms
Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 227	37½ fathoms
Eastern Gulf: Atlantis 1951 Station 154	64 fathoms

Distribution

Cape Verde Islands	10 fathoms
?Balears	46–48 metres
Florida	42 fathoms
John Adams' Bank, Brazil	
Galapagos Islands	10–12 fathoms
Galapagos Islands } Gulf of California }	0–100 fathoms

Genus *Escharina* Milne-Edwards, 1836

Escharina vulgaris (Moll)
(Pl. V, fig. 1)

Eschara vulgaris Moll (1803, var. α , p. 55, pl. 3, figs. 10A, B).

Schizoporella vulgaris (Moll) Hincks (1880a, p. 244, pl. 15, figs. 5, 6; pl. 37, fig. 7).

Schizolavella vulgaris (Moll) Canu and Bassler (1923, p. 108, pl. 35, fig. 10, *cum syn.*),
Osburn (1952, p. 335, pl. 38, fig. 13).

Escharina vulgaris Soule (1961, p. 15).

Material

Locality 69(18), 108(1).

Remarks

Our specimens agree in every respect with the numerous Madeiran specimens of *E. vulgaris* in the Norman Collection: 11.10.1.1176, 1179, except that in the latter the ovicell tends to develop a slight frontal callosity. This difference, even if it is real, can hardly be considered of specific importance.

E. vulgaris has only twice before been recorded from the Americas, first as a Pleistocene fossil from Santa Barbara, California, and, more recently, as living in the Gulf of California. The present find in the NW Gulf of Mexico clearly establishes the missing link with the main distribution of the species in the E Atlantic and Mediterranean.

Occurrence

North-western Gulf: Stetson Bank area	approx. 30 fathoms
Cavalier 1956 Station 302	15 fathoms

Distribution

E. Atlantic from Northern Ireland and the English Channel to the Cape Verde Islands	55–180 metres
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Mediterranean
Gulf of California

5-121 metres
1-47 fathoms

Fossil distribution

Pleistocene of Santa Barbara, California.

Genus *Cleidochasma* Harmer, 1957

Cleidochasma contracta (Waters)
(Pl. V, fig. 2)

Lepralia contracta Waters (1899, p. 11, pl. 3, figs. 4-6), Norman (1909, p. 303, pl. 41, figs. 5-6).

Lepralia contracta Waters var. *serrata* Osburn (1914, p. 211).

Lepralia serrata Osburn (1912, p. 242, pl. 26, fig. 57).

Perigastrella (*Lepralia*) *contracta* (Waters) Canu and Bassler (1920, p. 576).

Gemelliporella asper Canu and Bassler (1923, p. 110, pl. 18, figs. 5, 6), Canu and Bassler (1928a, p. 90, pl. 10, fig. 1).

Perigastrella contracta (Waters) Canu and Bassler (1929b, p. 403), Hastings (1930, p. 722, pl. 11, fig. 60), Marcus (1937, p. 98).

Hippoporina contracta (Waters) Osburn (1940, p. 428), Osburn (1947, p. 33), Rogick and Croasdale (1949, p. 57, figs. 34-41), Osburn (1952, p. 346, pl. 41, figs. 4, 5), Maturo (1957, p. 52, text-fig. 57).

Cleidochasma contracta Soule (1961, p. 19).

Material

Locality 2(38), 23(4), 36(1), 55(2), 77(2), 78(1), 80(1), 94(46), 99(24), 100(1), 102(1), 111(5), 115(4), 150(14), 179(1), 180(1), 181(6), 353(2), 354(8), 356(2), 358(1), 359(1), 383(1), 384(6), 387(1), 388(2), 389(4), 390(1), 391(3), 392(1), 393(2), 394(1), 395(3), 396(2), 399(1), 401(1), 403(1), 413(1), 414(2), 415(4), 416(8), 417(1), 419(12), 420(3), 424(2), 426(13), 427(5), 428(25), 429(15), 430(6), 431(3), 432(3), 434(9), 444(3).

Remarks

This species does not constitute a new addition to the Gulf fauna since it was previously recorded by Osburn (1914, p. 211) from the Tortugas as *Lepralia contracta* Waters var. *serrata* Osburn. It is included in this paper for the following reasons: 1) it has not been figured before from the Gulf of Mexico; 2) to call attention to the interesting addition of a North American younger Tertiary species to its synonymy; 3) it provides an opportunity to discuss the status of the genus *Gemelliporella* Canu and Bassler.

In its general aspect *Gemelliporella asper* Canu and Bassler 1923, from the Miocene and Pliocene of the southern United States and later (1928a) recorded as a Recent form from Albatross Station D.2322, north of Cuba, 115 fathoms, is strikingly similar to the Recent *Cleidochasma contracta* (Waters). Unfortunately several critical details are not apparent from the original description and figures in the 1923 monograph. In order to establish the identity beyond all doubt, it was necessary to find out whether or not the fossil species featured: 1) a finely beaded vestibular arch; 2) bifid lateral condyles; 3) a semicircular, non-calcified area on the frontal part of the ovicell; 4) occasional large, spathulate avicularia with complete cross-bar and columella.

I am indebted to Dr. A. C. Smith, Dr. G. Arthur Cooper, and Dr. R. S. Boardman of the United States National Museum for the loan of the following specimens:

- a) the single, Recent "Plesiotype" specimen (U.S.N.M. Cat. No. 7533) from Albatross Station D.2322, north of Cuba, 115 fathoms, described and figured by Canu and Bassler (1928a, p. 90, pl. 10, fig. 1) as *Gelliporella asper*. This specimen very clearly shows all the characters mentioned under 1), 2), 3) and 4).
- b) fourteen Recent specimens (U.S.N.M. Cat. No. 9753, 9758), labelled "*Gemelliporella aspera* [sic] C & B" in Dr. Bassler's handwriting, from "Atlantic—50 fms. Sta. 104 near San Juan, Porto Rico." This is presumably Caroline 1933 Station 104, from 80–120 fathoms; see Bartsch, 1933, p. 29. These specimens also show the four characters mentioned under 1), 2), 3), and 4).
- c) A Pliocene topotype specimen of *Gemelliporella asper* from the Waccamaw marl, Waccamaw River, Horry County, South Carolina. This specimen, which encrusts an oyster fragment, shows very well characters 2), 3) and 4), but the minute beads along the vestibular arch are not on the whole clearly apparent. Their presence could be definitely established in only a few of the many orifices. In general aspect this Pliocene topotype specimen of *Gemelliporella asper* closely resembles some of our Recent Tampa Bay specimens of *Cleidochasma contracta* (predominance of small, globular avicularia; conspicuous areolar pores).
- d) Five Pliocene specimens of *Gemelliporella aspera* [sic] C & B from the Caloosahatchee marl of Shell Creek, De Soto County, Florida, all showing characters 2) and 4), whereas 3) is only apparent in the largest specimen. The vestibular arch of almost all the orifices is perfectly smooth, but in the largest specimen there are also a few orifices with distinct beads.

From these observations it appears that the Recent Cuban form of *Gemelliporella asper* Canu and Bassler is identical with *Cleidochasma contracta* (Waters). It is interesting to observe that Dr. Hastings has identified as specimen from Havana as *?Perigastrella contracta* (11.10.1.1114, "Blake," 80 fathoms, Norman Collection). The Pliocene specimens of *G. asper* differ from *C. contracta* in the vestibular arch being only occasionally beaded. This difference, even if it is real, can hardly be considered of specific importance.

Occurrence

North-western Gulf: numerous stations	6–70 fathoms
Eastern Gulf: numerous stations	3 $\frac{2}{3}$ –34 fathoms

Fossil occurrence

Pleistocene of Shell Oil Company offshore well St. Tr. 448 #1, Kain Field, Matagorda County, Texas, in ditch cuttings from the interval 770–800'.

Distribution

Madeira	
North American Atlantic coast from Cape Cod, Mass. to Beaufort, North Carolina and near the Tortugas	5–20 fathoms
North of Cuba	80–115 fathoms
Bay of Santos, Brazil	down to 20 metres
American Pacific coast from the Gulf of California to Ecuador	
Galapagos Islands	10–30 fathoms

Fossil distribution

Miocene (Choctawhatchee marl) of Jackson Bluff, Ocklocknee River, Florida;
Pliocene (Waccamaw marl) of Waccamaw River, Horry County, South Carolina;
Pliocene (Caloosahatchee marl) of Shell Creek, De Soto County, Florida.

Note on the status of the genus Gemelliporella Canu and Bassler

Canu and Bassler (1919, p. 92; 1920, p. 372) have twice introduced *Gemelliporella*, with widely different type species. Whereas Harmer (1957, p. 1039), in accepting the 1920 version, rejected by implication the earlier introduction, it is here maintained that the 1919 introduction was perfectly valid. Although no diagnosis of the genus was given in 1919, a single species, *Gemelliporella punctata* Canu and Bassler, from the upper Middle Miocene of Bowden, Jamaica, was described and figured. That species is therefore the type species by monotypy.

Gemelliporella Canu and Bassler, 1919 has, therefore, valid standing. The generic diagnosis should read as follows: Ascophora. Zoarium erect, branching, cylindrical, consisting of six longitudinal rows of zooecia. Orifice keyhole-shaped. Frontal wall a tremocyst. Avicularia small, frontal, the subcircular rostrum slightly raised and tilted. Ovicells hyperstomial, deeply imbedded in the cylindrical zoarium, with a fairly large circular opening in front, not closed by the operculum.

Its geological range is Middle Miocene-Recent. The Recent representative in the Gulf of Mexico is *Gemelliporella glabra* (Smitt). Canu and Bassler (1928a, p. 99) implied that this species is congeneric with the Miocene type when they stated: "The zoarium of *Gemellipora* [sic] *punctata* Canu and Bassler, 1923, is identical but the present species differs from it in its smaller and more scattered apertures."

It is interesting to observe that Smitt himself (1873, p. 38) considered the introduction of a separate genus for *G. glabra*: "... would induce us to make it a new genus, if we knew any more species, which were to be placed in a closer relation to the *G. glabra*," but then rejected the idea.

Gemelliporina was introduced by Bassler (1936, p. 161) with *Gemellipora glabra* as the type species. It is obvious that *Gemelliporina* Bassler, 1936 is a junior synonym of, and should lapse in favour of, *Gemelliporella* Canu and Bassler, 1919.

Family HIPPOPORINIDAE BROWN, 1952

Genus *Hippoporella* Canu, 1917*Hippoporella gorgonensis* Hastings

(Pl. V, fig. 3)

?Lepralia uvulifera Osborn (1914, p. 210, text-figs. 19, 20).

Hippoporella gorgonensis Hastings (1930, p. 723, pl. 12, figs. 62-72; pl. 17, figs. 119, 121). Marcus (1937, p. 99, pl. 19, figs. 53A, B), Marcus (1938b, p. 220, text-fig. 20). Osburn (1952, p. 348, pl. 45, figs. 10-12), Soule (1961, p. 20).

Material

Locality 76(5), 78(3), 80(1), 120(1), 179(1), 353(2), 354(10), 356(1), 359(3), 360(2), 361(1), 392(5), 393(1), 413(1), 414(1), 415(2), 417(2), 419(4), 420(2), 422(2), 424(14), 426(4), 428(7), 430(2), 442(2).

Remarks

As Dr. Hastings has shown, this is an exceedingly variable species. The various aspects

of the zooecia do not only reflect their age and position within the colony, but also correlate to some extent with salinity and depth. Adult (fertile) specimens with a well-developed median mucro bearing branch-processes, and with numerous lateral avicularia, such as shown in Pl. V, fig. 3, occur offshore in the Eastern Gulf at depths of 7–23 fathoms and a salinity of approximately 36 ‰. Such specimens closely resemble the type figures 63 and 64 of *H. gorgonensis*, except that they have as many as six spine-bases on the distal peristome. In lower Tampa Bay and in the Egmont Channel, on the other hand, in depth of $5\frac{5}{6}$ –7 fathoms and at salinities of 30–35 ‰, only specimens of a more simple design are found, with a rudimentary mucronate process and usually lacking avicularia. The Heald Bank specimens are also of this simple type.

The possibility of *H. gorgonensis* being a synonym of *Lepralia uvulifera* Osburn is not to be ruled out. The original descriptions of the two forms have much in common, Hastings's account and figures being superior but of later date, and the specimens in hand meet the crucial points in either description. The recorded depth range—an important part of the specific diagnosis—of *H. gorgonensis* in the Galapagos Islands is 0–15 fathoms, and along the Pacific coasts of Panama and Colombia again 0–15 fathoms. The Gulf species here referred to *H. gorgonensis* occurs between $5\frac{5}{6}$ and 23 fathoms on the Florida shelf. *L. uvulifera* was originally recorded from the Tortugas, Florida, some 175 nautical miles further south, at 10 fathoms. A final verdict clearly hinges on a reappraisal of Osburn's single type specimen.

Occurrence

North western Gulf: Heald Bank Dredge sample	8 $\frac{1}{3}$ fathoms
Cavalier 1956 Station 331	6 $\frac{2}{3}$ fathoms
Cavalier 1956 Station 329	6 fathoms
Cavalier 1956 Station 291	4 fathoms
Cavalier 1956 Station 179	37 $\frac{1}{2}$ fathoms
Eastern Gulf: numerous stations	5 $\frac{5}{6}$ –23 fathoms

Distribution

Bay of Santos, Brazil	0–20 metres
St. Helena	36–39 metres
Jicarón Island, Taboga, Coiba, Panama	0–12 fathoms
Gorgona, Colombia	0–15 fathoms
Galapagos Islands	0–15 fathoms
American Pacific coast from Southern California to the Galapagos Islands	0–82 fathoms

Genus *Hippodiplosia* Canu, 1916

Hippodiplosia americana (Verrill)
(Pl. V, fig. 4)

Lepralia americana Verrill (1875, p. 415, pl. 7, fig. 4, non fig. 5 = *Cryptosula pallasiana* Moll sp.), Osburn (1912, p. 241, pl. 25, figs. 55, 55a, cum syn.).

Hippodiplosia americana Hastings (1930, p. 725, pl. 11, fig. 61), Osburn (1933, p. 40, pl. 14, figs. 6, 7), Marcus (1937, p. 101, pl. 20, figs. 54A, B), Osburn (1952, p. 339, pl. 40, fig. 4), Maturo (1957, p. 51, text-fig. 56).

Material

Locality 4(1), 5(8), 14(1).

Remarks

The North American distribution of this species resembles that of the hydroid *Tubularia crocea* (Agassiz) (see Deevey, 1950, text-fig. 3) in that it provides another example of discontinuous distribution around the Florida Peninsula (Fig. 3). Disjunct distribution patterns of this type have been attributed by Deevey (*l. c.*) to the existence of a thermal barrier which would prohibit the dispersal of boreal Atlantic species around the Peninsula. According to Deevey, the hydroid *Tubularia crocea*—and this might apply as well to the bryozoan *Hippodiplosia americana*—“is to be regarded as a relict of a glacial age of the Pleistocene, when free migration of boreal species from the Atlantic to the Gulf coast was entirely practical.” However, the validity of this hypothesis, with its strong accent on temperature as the controlling factor, is seriously impaired by the known occurrences of *T. crocea* at Panama and the Galapagos Islands, and by the occurrences of *H. americana* at these two localities, as well as at Santos, Brazil and in the Gulf of California. These records from subtropical or tropical regions cannot be explained away by simply promoting the tropical form to the rank of “physiological subspecies,” morphologically identical with, but physiologically different from the boreal species (Deevey, *l. c.*, p. 356).

Hedgpeth, in his illuminating paper on the Zoogeography of the Northwestern Gulf of Mexico (1953), has shown (*l. c.*, p. 199–200) that disjunct distribution is by no means rare among several groups of marine organisms recorded from Texas and Louisiana, and not necessarily limited to temperate species. Furthermore, Hedgpeth has somewhat reduced the unequal appraisal of salinity with respect to temperature as a factor controlling disjunct distribution, stating (*l. c.*, p. 203): “Other species may be absent from south Florida because suitable estuarine (*i.e.* euryhaline) conditions are lacking.”

In my opinion a simple explanation for the absence from Florida and the North-eastern

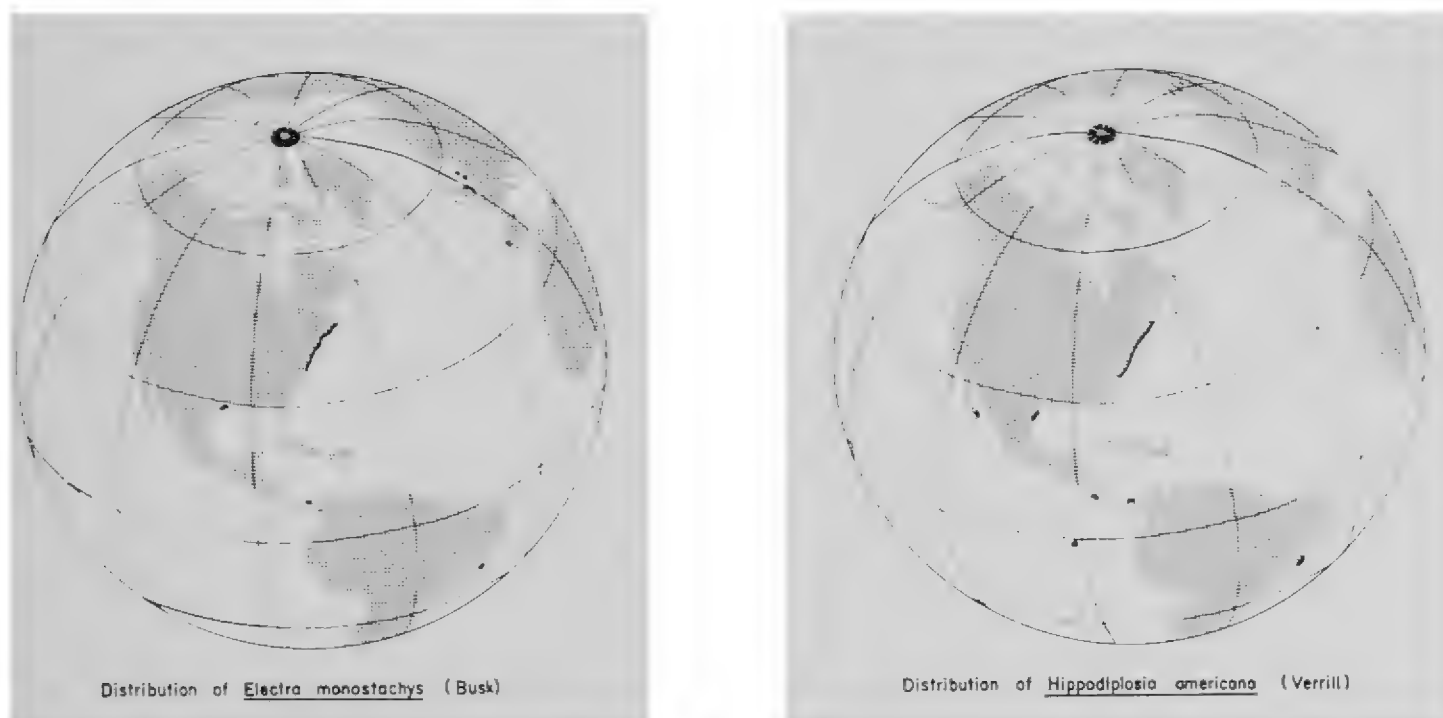


FIG. 3. Examples of disjunct distribution of Bryozoan species along the American Atlantic and Gulf coasts.

Gulf of the two disjunct bryozoan species *Hippodiplosia americana* and *Electra monostachys* is to be found in the coordination of the following facts:

- 1) around the southern half of the Florida Peninsula salinities, even those of the very shallow inshore waters, are high (in the order of 36‰ or more) and remarkably constant throughout the year; cf. data for Fowey Rocks, presented by Dole and Chambers (1918), and graphs illustrating "hydrographic climate" at Key West by Hedgpeth (*l. c.*, p. 145).
- 2) In the Northwestern Gulf *H. americana* and *E. monostachys* occur only in those inshore and very shallow offshore waters whose monthly average salinity remains generally < 30 ‰ throughout the year: Corpus Christi Bay, Aransas Bay, San Luis Pass, Galveston Island, and off the mouth of the Brazos River. In other words, the disjunct Bryozoa are typically brackish (polyhaline) species.

It is an established fact that several other invertebrate species which have been cited as typical examples of disjunct Atlantic-Gulf distribution, such as the marsh crab *Sesarma reticulatum*, the salt marsh periwinkle *Littorina irrorata*, the American oyster *Crassostrea virginica* and several other pelecypods, *e.g.*, *Abra aequalis*, *Rangia cuneata*, and *Polymesoda caroliniana*, all inhabit low salinity biotopes.

It seems, therefore, that the barrier to free dispersal around the Florida Peninsula is of a saline rather than a thermal nature. This view does not invalidate Deevey's glacial relict hypothesis. On the contrary, the possibility that some of the disjunct species in the NW Gulf are true glacial relicts in Deevey's sense is real, distribution having been continuous during interglacial periods when Florida was submerged and the polyhaline inshore waters of the Northern Gulf merged with those extending along the Atlantic coast of Georgia and the Carolinas.

Occurrence

North-western Gulf:

Corpus Christi Bay, Texas

$\frac{2}{3}$ – $\frac{5}{6}$ fathom

Mud Island, Aransas Bay, Texas

$\frac{5}{6}$ –1 fathom

Distribution

North American Atlantic coast from Mt.

Desert Island, Maine, to Beaufort, North Carolina

Bay of Santos, Brazil

20 metres

Balboa, Panama Canal Zone

buoy

Agua Verde Bay, Gulf of California

Port Culebra, Costa Rica

Galapagos

10–30 fathoms

Family EXOCHELLIDAE BROWN, 1952

Genus *Exochella* Jullien, 1888

Exochella longirostris Jullien

(Pl. V, fig. 5)

Mucronella tricuspis Hincks: Busk (1884, p. 159, pl. 22, fig. 3, *non Mucronella tricuspis* Hincks, 1881b, p. 125, pl. 3, fig. 1).

Exochella longirostris Jullien (1888, p. 55, pl. 3, figs. 1–4; pl. 9, fig. 2), Calvet (1904, p. 29), Marcus (1937, p. 82, pl. 17, fig. 43, *cum syn.*), Marcus (1941b, p. 22, fig.

16), Marcus (1949, p. 1), Mawatari (1952, p. 265), Rogick (1956, p. 123, figs. 1A-J).

Material

Locality 99(3).

Remarks

Complete coalescence of the proximal bifid median denticle with the pair of lateral teeth in the secondary orifice, resulting in two independent rounded pores or tubes, has been described from *Exochella tricuspis* Hincks sp. (Waters, 1906, p. 20; Levinsen, 1909, p. 320) and also from *Exochella longirostris* Jullien (Waters, 1889, p. 15; Waters, 1906, p. 20). In *E. tricuspis*, however, the areolar pores are often difficult to observe and the avicularia are very consistent in their paired occurrence and lateral orientation (e.g., the lectotype specimen, 99.5.1.883, from Curtis Island, Bass Straits; or 97.5.1.918, from Western Port, Victoria). In *E. longirostris* the marginal areolae are very conspicuous even in the young zooecia and separated by projecting ribs in the older ones and the avicularia are often single and sometimes entirely absent and they are not quite as regularly arranged. In these characters the Gulf specimens definitely resemble *E. longirostris*.

Matters are complicated by the fact that Busk's figured specimen (87.12.9.635, from Prince Edward Island) and another Challenger specimen (87.12.9.637, from Challenger Station 315) are not identical with *E. tricuspis* (Hincks), although they were identified as such (Busk, 1884, p. 159, pl. 22, fig. 3). Their morphological characters point to *E. longirostris* Jullien. This view is supported by the following facts:

- 1) Although Busk (1884, p. ix) identified the only *Mucronella* among the 15 species of Bryozoa from Challenger Station 315 as *Mucronella tricuspis* Hincks, Levinsen (1909, p. 321, pl. 17, figs. 6a, b) described and figured "A small colony from the Challenger St. 315" as *Exochella longirostris* Jullien.
- 2) A slide bearing a specimen from West Point Island, West Falklands (30.1.16.12) is labelled "*Mucronella tricuspis* Busk Chall. XXX p. 159 not Hincks" in Dr. A. B. Hastings' handwriting. This and another specimen from Cape Orford, Port Stephens, West Falklands (30.1.16.5) are probably the "Recent specimens of *E. longirostris* Jullien from the Falkland Islands in the Zoological Department collections" referred to by Brown (1952, p. 289) as giving evidence for the umbonuloid structure of the frontal wall in *Exochella*.

The occurrence of *E. longirostris* in the NW Gulf of Mexico is rather unexpected, as the known distribution of this species was hitherto limited to the Southern Hemisphere, S of the 20° parallel, with the exception of one record from Japan.

Occurrence

North-western Gulf: Cavalier 1956 Station 311	70 fathoms
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Distribution

Magellan Region	19 metres
Falkland Islands	12 metres
Chatham Islands	
Prince Edward Island	80–150 fathoms
Cape of Good Hope	

Bay of Santos, Brazil	down to 20 metres
Santa Catharina Island, Brazil	
Guaratuba, Brazil	
Espírito Santo, S of Victoria, Brazil	35 metres
Marguerite Bay, Antarctica	85–100 fathoms
Kii Peninsula, Japan	

Fossil distribution

Post-Pampean (Holocene), Puerto Militar, Bahía Blanca, Argentine.

Family SMITTINIDAE LEVINSEN, 1909

Genus *Smittoidea* Osburn, 1952

Smittoidea reticulata (Macgillivray)

(Pl. VI, fig. 1)

Lepralia reticulata Macgillivray (1842, p. 467).

American records:

non Smittia reticulata Robertson (1908, p. 306, pl. 23, figs. 75, 76 = *Smittoidea prolifica* Osburn).

Smittina reticulata Canu and Bassler (1930, p. 27).

Smittoidea reticulata Osburn (1952, p. 409, pl. 48 figs. 9, 10), Soule (1961, p. 34).

Material

Locality 99(5).

Remarks

Our specimens have been compared with ovicelled British specimens of *S. reticulata* (e.g., 99.5.1.916, Britain, Hincks Collection). Except for the occasional presence of two spine bases in the distal gap of the peristome in the latter, the similarity is perfect.

Previous American records of *S. reticulata* are from the Galapagos Islands, from the Gulf of California, and from the Falkland Islands.

Occurrence

North-western Gulf: Cavalier 1956 Station 311 70 fathoms

American distribution

Galapagos Islands	}	17–150 fathoms
Gulf of California		
Falkland Islands		

Genus *Codonellina* Bassler, 1934

Codonellina montferrandii (Audouin)

(Pl. VI, fig. 3)

Flustra montferrandii Audouin (1826, p. 240), Savigny (pl. 9, fig. 14).

Codonellina anatina (Canu and Bassler) Osburn (1952, p. 422, pl. 46, figs. 14, 15).

Codonellina montferrandii Harmer (1957, p. 1049, pl. 69, figs. 25, 26, 30, *cum syn.*).

Material

Locality 94(15).

Remarks

This species has its main distribution in the tropical Indo-Pacific, where it is widely distributed: Red Sea, Ceylon, Wasin (British East Africa), Malay Archipelago, Philippines, Japan, Australia, Hawaii, Galapagos Islands, Gulf of California.

Osburn (1952, p. 422) indicates the presence of spathulate avicularia in his specimens of *C. anatina* from the Gulf of Mexico, but it is obvious that this was a slip of the pen since he was discussing material from the Gulf of California.

Occurrence

North-western Gulf: Cavalier 1956 Station 316 50 fathoms

American distribution

Galapagos Islands 0-40 fathoms
Gulf of California

Genus *Parasmittina* Osburn, 1952

Parasmittina signata (Waters)
(Pl. VI, fig. 2)

Smittia signata Waters (1889, p. 17, pl. 3, figs. 4-6).

Schizopodrella horsti Osburn (1927, p. 127, text-figs. 3-5).

Schizoporella horsti (Osburn) Marcus (1937, p. 87, pl. 18, fig. 46), Marcus (1939, p. 139, pl. 9, fig. 13).

Lacerna horstii (Osburn) Osburn (1940, p. 426), Osburn (1947, p. 31).

Smittina signata Harmer (1957, p. 928, pl. 63, figs. 27-29, *cum syn.*).

Material

Locality 23(1), 76(1), 94(1), 99(1), 113(1), 145(29), 179(1), 354(1), 380(1), 382(1), 384(2), 388(2), 389(1), 390(2), 416(1), 424(1), 426(4), 428(1).

Remarks

Parasmittina signata (Waters), originally described from Port Jackson, New South Wales, has a wide distribution in the Indian Ocean and Western Pacific. The identity of our Gulf specimens has been established by direct comparison with Australian specimens in the collections of the Zoological Department of the British Museum (N.H.): 34.11.12.65, a Challenger specimen from Australia?, and 32.4.20.51, from the Great Barrier Reef. The discovery of this species in the Gulf of Mexico leads further support to Harmer's tentative suggestion (1957, p. 930), that *Schizopodrella horsti* Osburn, from the Caribbean and Brazil, is a synonym of *Parasmittina signata*.

Occurrence

North-western Gulf: Cavalier 1956 Station 12 8½ fathoms
Heald Bank Dredge sample 8½ fathoms
Cavalier 1956 Station 316 50 fathoms
Cavalier 1956 Station 311 70 fathoms
Cavalier 1956 Station 297 9 fathoms
Cavalier 1956 Station 273 24 fathoms
Cavalier 1956 Station 227 37½ fathoms

Eastern Gulf:	off Choctawhatchee Bay	12½ fathoms
	off Cedar Keys	17–43 fathoms
	Lower Tampa Bay—Egmont Channel	6–7 fathoms
	off Egmont Key	10½ fathoms

Distribution

Suez	
Indian Ocean	125 fathoms
Malay Archipelago	0–275 metres
Philippines	186–530 fathoms
Japan	
Great Barrier Reef	13½ fathoms
New South Wales	
Adelaide	20–35 fathoms
Tahiti	
Curaçao	} 17–23 fathoms
Colombia	
Venezuela	
Puerto Rico	5–8 fathoms
Bay of Santos, Brazil	0–20 metres

Genus *Phoceana* Jullien, 1903

Phoceana acadiana sp. nov.
(Pl. VI, fig. 7)

Holotype

Locality 469 (large specimen, measuring 9.7 mm in length). USNM 648044.

Paratypes

Locality 412(4). USNM 648045 (figured), 648046.

Locality 469(3). USNM 648047.

Other material

Locality 458(18), 461(1).

Diagnosis

Phoceana with the zooecia arranged in four longitudinal rows throughout the zoarium. Peristome long and tapering, making an acute angle with the zoarial branch, its rim not everted or thickened. Interior wall of peristome smooth, without proximal ridge.

Description

Zoarium erect, consisting of a long, slender stem which gives off occasional branches at almost right angles. *Zooecia* alternating in four longitudinal rows throughout the zoarium, well defined exteriorly by distinct sutures. *Primary orifice* invisible from the outside. *Secondary orifice* sub-circular. *Peristome* long and tapering when complete, making an acute angle with the zoarial branch, its rim not everted or thickened. *Frontal wall* an olocyst, covered by a white tremocyst, and bordered by a small number of mar-

ginal pores. *Avicularia* lacking. *Ovicells* hyperstomial, globular, lodged in the acute angle between the peristome and the outer wall of the zoarial branch.

Measurements

	Holotype	Figured paratype
	Lz = 0.90 — 1.10 mm	Lz = 1.— mm
	lz = 0.45 mm	lz = 0.45 mm
diameter of secondary orifice = 0.12 — 0.15 mm		= 0.15 mm

Remarks

The four Oregon specimens stand out by their fine preservation and by the possession of ovicells. The largest zoarial fragment measures 9.7 mm. The peristomes are considerably more produced than in the *Vema* specimens and are almost transparent. Several of the amber-coloured opercula are still *in situ*. The frontal is an olocyst, with irregular patches of white tremocyst preserved in the *Vema* specimens. The specimens taken off Molasses Reef Light, although badly altered, are interesting because they show the mode of branching which occurs almost at right angles to the main branch.

The diagnosis given above summarizes those characters which distinguish this species from *Phoceana columnaris* Jullien, the type species (by monotypy) of *Phoceana* Jullien, 1903, itself a deeper water species (100–445 m) from the Eastern Atlantic and the Western Mediterranean. I have compared my specimens with a Mediterranean specimen of *P. columnaris* (St. 1292, SW of Alboran Island, 100–115 m), which Dr. Y. V. Gautier (Marseilles) has kindly made available.

Occurrence

Eastern Gulf: Vema-3 1954 Station BT #2	96 fathoms
Florida Straits: off Molasses Reef Light	122 fathoms
off Carysfort Light	78 fathoms
NW of Cay Sal Bank	150 fathoms

Family LEKYTHOPORIDAE LEVINSEN, 1909

Genus *Lekythopora* MacGillivray, 1883

Lekythopora longicollis sp. nov.
(Pl. VI, figs. 4–5)

Holotype

Locality 99 (cluster of six zooecia, one with ovicell). USNM 648048.

Paratypes

Locality 99(8). USNM 648049 (figured), 648050.

Other material

Locality 68(1), 69(1), 70(2), 72(1), 94(3), 150(2), 444(2).

Description

Zoarium presumably encrusting a perishable substratum. *Zooecia* small, flask-shaped, in small clusters of 3–9 zooecia. *Frontal wall* convex, evenly but not very densely perfo-

rated by rather coarse tremopores, not verrucose. *Peristome* smooth, long and slender and hardly flaring distally. The volume of the peristome of a fully produced peristome is only slightly less than that of the adnate part of the zooecium. The change from the porous tremocyst to the smooth peristome is abrupt and the peristome is often somewhat constricted at this point. A pair of minute, acute, triangular *avicularia* is inserted in the lateral rim of the peristome, but they are not always easy to observe. They extend downwards along the peristomial wall as long and narrow tubular chambers. The *ovicells* are small, perched high above the base of the peristome, and have a large crescentic densely porous frontal area.

Measurements

Holotype and paratypes	
Lz (incl. peristome)	= 0.40–0.58 mm (sterile zooecia)
Lz (incl. peristome)	= 0.62–0.70 mm (fertile zooecia)
lz	= 0.18–0.30 mm
ho (second. orifice)	= 0.08–0.12 mm
lo (second. orifice)	= 0.08–0.12 mm

Remarks

This appears to be a fairly common species in the North-western Gulf of Mexico. Among the American species of '*Lagenipora*' the new species resembles '*L.* *marginata* Canu and Bassler (1930, p. 36, pl. 6, figs. 2, 3), from the Galapagos Islands, in several ways. As ascertained on the three topotypes of '*L.* *marginata* in the collections of the Zoological Department, British Museum (N. H.), 33.12.10.16, from Albatross Station D.2813, 40 fathoms, the latter is a larger species, however, with a more densely perforated tremocyst and with the ovicell "always fixed at the base of the peristome."

Occurrence

North-western Gulf:

Vema-3 1954 Core #65	30 fathoms
vicinity of Stetson Bank	approx. 30 fathoms
Univ. of Houston sample 15	29 fathoms
Univ. of Houston sample 12	31 1/3 fathoms
Cavalier 1956 Station 316	50 fathoms
Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 278	38 fathoms

Eastern Gulf:

SSW of John's Pass, Florida	34 fathoms
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Family CREPIDACANTHIDAE LEVINSEN, 1909

Genus *Crepidacantha* Levinsen, 1909

Crepidacantha poissonii (Audouin) var. *teres* Hincks

(Pl. VI, fig. 6)

Lepralia kirchenpaueri Heller var. *teres* Hincks (1880b, p. 77, pl. 9, figs. 7, 7a).

Crepidacantha poissonii var. *teres* Brown (1954, p. 247, text-figs. 1A, B, cum syn.).

American records:

Crepidacantha poissonii Canu and Bassler (1928a, p. 136, pl. 34, fig. 3), Canu and Bassler (1930, p. 33, *non* pl. 5, fig. 5 = *Crepidacantha solea* Canu and Bassler).

Crepidacantha poissoni Osburn (1940, p. 451), Osburn (1952, p. 478, pl. 58, fig. 2).

Material

Locality 99(1), 101(1), 179(2).

Remarks

Our specimens compare in every detail with specimens from Madeira in the Norman Collection: 11.10.1.783, 784, 785, which belong to this variety (*vide* Brown, 1954, p. 247).

As pointed out by Canu and Bassler (1928, p. 136, 137; 1930, p. 33), the paired vibracula are often placed asymmetrically on the frontal wall. This arrangement is also apparent in our Gulf specimens, as well as in the specimens from Madeira referred to above. Moreover, one of the vibracula is often somewhat larger than the other of the same pair, as is well shown in Osburn's figure (1952, pl. 58, fig. 2).

I depart slightly from Brown's recent review of the genus in including the material from the Galapagos Islands, identified by Canu and Bassler (1930, p. 33) as *C. poissonii*, as well as Osburn's material of *C. poissoni* from the American Pacific coast, in the present variety rather than in *Crepidacantha solea* Canu and Bassler (*cf.* Brown, 1954, p. 253). In *C. poissonii* var. *tres* the proximal lip of the orifice is straight or only slightly convex, and Osburn (1952, p. 478) describes this feature in his American Pacific coastal specimens as "straight." In *C. solea*, a species originally described from the China Sea, the proximal lip of the orifice is distinctly produced (and "square, plate-like"), which affects the entire shape of the orifice. On this character the specimen from Hawaii figured as *C. poissonii* by Canu and Bassler (1928b, pl. 8, fig. 7; 1930, pl. 5, fig. 5) might well remain in *C. solea* where Brown placed it.

Occurrence

North-western Gulf: Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 309	57 fathoms
Cavalier 1956 Station 227	37½ fathoms

Distribution

Funchal Bay, Madeira	30 fathoms
Cape Verde Islands	110–180 metres
Bermuda	
Puerto Rico	6 fathoms
Galapagos Islands	33½–40 fathoms
Pacific coast of America between Santa Barbara Island, off Southern California, and La Libertad, Ecuador	} 0–73 fathoms

Fossil distribution

Pliocene of Bocas Island, Almirante Bay, Panama.

Family VITTATICELLIDAE HARMER, 1957

Genus *Vittaticella* Maplestone, 1901

Vittaticella uberrima Harmer

(Pl. VII, figs. 1-2.)

?*Vittaticella elegans* (Busk) Osburn (1940, p. 464, pl. 9, figs. 78, 79, *non Catenicella elegans* Busk, 1852, p. 361, pl. 1, fig. 2).

Vittaticella uberrima Harmer (1957, p. 772, pl. 50, figs. 4, 5, 15, *cum syn.*).

Material

Locality 111(10).

Remarks

Although the few isolated internodes from Cavalier 1956 Station 299 in the North-western Gulf of Mexico do not consist of more than two zooecia each, and although gigantic avicularia of the type described by Harmer have not been found, comparison with Harmer's Siboga material leaves me satisfied that the Gulf specimens belong to *V. uberrima*. The zooecia are long and slender, the vittae are lateral, the ovicell features a single row of pores around the distal margin of the entooecium, and the lateral processes are not cusped distally, but transverse.

With regard to *Vittaticella elegans* (Busk) Harmer (1957, p. 770) has stated "*V. elegans* occurs commonly on the southern coast of Australia and off New Zealand; extending at least as far north as New South Wales. I have no evidence that it reaches tropical waters; and various records of this species outside the area above indicated may be disregarded." This also affects the American records of *V. elegans* (Busk, 1884, p. 12; Correa, 1947, p. 1; Osburn, 1940, p. 464; 1952, p. 286).

As Osburn (1940, p. 464) observed giant avicularia with a long spatulate mandible in Puerto Rican specimens of "*V. elegans*," there is reason to believe that they also belong to *V. uberrima*, the position of the adzooecial vittae in Osburn's pl. 9, fig. 78 probably being inaccurate.

Occurrence

North-western Gulf: Cavalier 1956 Station 299	111 $\frac{1}{6}$ fathoms
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Distribution

Australia	
Malay Archipelago	0-88 metres
Zanzibar	0-10 fathoms
?Algoa Bay, South Africa	
?Ceylon	
?Puerto Rico	5-30 fathoms

Family SAVIGNYELLIDAE LEVINSEN, 1909

Genus *Halysisis* Norman, 1909

Halysisis diaphana (Busk)

(Pl. VII, fig. 3)

Scruparia diaphana Busk (1860b, p. 281, pl. 31, fig. 1).

Halysisis diaphana Harmer (1957, p. 764, pl. 51, fig. 22, *cum syn.*).

Material

Locality 382(2), 389(1), 390(1).

Remarks

The ovicell, with the two large frontal pores, was first described and figured by Waters (1913). Two of our fragmentary specimens include part of an ovicelled zooecium, but unfortunately in each case the frontal part of the ovicell is broken off.

Occurrence

Eastern Gulf: Atlantis 1951 Stations 157, 164, 165 17, 34 fathoms

Distribution

Madeira	no depth given
Cape Verde Islands	52–219 metres
St. Paul's Rocks (Challenger Station 109)	shallow water
Zanzibar	8–10 fathoms
Malay Archipelago	0–45 metres
?Japan	30–35 fathoms

Incertae sedis

Genus *Fedora* Jullien, 1883

Fedora nodosa Silén

(Pl. VII, figs. 4–5)

Fedora nodosa Silén (1947, p. 53, text-figs. 41–45, pl. 4, figs. 22, 23).

Material

Locality 68(2, 72(1), 93(10), 94(8), 99(1), 101(4), 102(13), 103(3), 104(7), 150(30), 177(1), 178(1), 179(8), 181(8), 332(21), 351(1), 368(17), 369(24), 377(7), 378(3), 379(6), 380(9), 381(2), 382(14), 383(5), 384(2), 385(1), 386(19), 411(4), 412(12), 443(1), 458(15), 458a(2), 464(3).

Remarks

This is clearly one of the more common species in the Gulf of Mexico and it is remarkable that it should have escaped the attention of earlier workers until Silén eventually described it in 1947.

In order to facilitate a more detailed discussion of this interesting species, our Gulf specimens may be conveniently arranged in four categories:

- A. Small, juvenile colonies consisting of three to approximately eight zooecia. They are usually "free," but incrusting specimens are found occasionally (Cavalier 1956 Stations 278, 316; Atlantis 1951 Station 158; Vema-3 1954 Dredge #1).
- B. Larger, incrusting zoaria, generally growing on and around small foreign calcareous objects, and tending to attain an ovoid or spindle shape with advancing growth. Almost complete incorporation of the small object into the axial part of the semi-ovoid or hemispherical colony is seen in specimens from the following samples: Vema-3 1954 BT #2, off Molasses Reef Light and Cavalier 1956 Station 278, from 96, 122 and 38 fathoms, resp.
- C. Larger, semi-ovoid or hemispherical colonies with exposed axial cavity. In some colonies this cavity is wide open, in others it is narrow, but its shape is always irregular and its wall hummocky and uneven. In these zoaria there is nothing to suggest incrustation on solid objects. One could visualise colonial growth taking place on

and around small lumps of hardened mud, which would explain the irregular shape of the cavity.

- D. Complete ovoid or spindle-shaped zoaria with the axial cavity, if any, sealed off and concealed by further growth. This category is clearly the more advanced stage of C. Judging from the orientation of the orifices, the blunt part of the ovoid or spindle is the proximal, the tapering end the distal side of the colony. The arrangement of six zooecia radiating from the "emanation-point of zoid rows" (cf. Silén, 1947, text-fig. 44) is always found on the blunt, proximal side.

The zooecia and orifices of category A are slightly smaller than those of categories B, C and D, but this is what may be expected in juvenile colonies. As all the zooecia, irrespective of zoarial category, are characterized by 1) a hippoporine orifice, 2) an open "special chamber" distally to the orifice, 3) the lack of ovicells, 4) a coarsely tuberculated frontal wall, and 5) the occasional presence of a small lateral avicularium, one is forced to conclude as to the identity of all four categories A, B, C and D. Categories C and D have been described as *Fedora nodosa* Silén (1947, p. 53, pl. 4, figs. 22, 23) from Albatross Station D.2398, 227 fathoms, in the NE Gulf of Mexico (Silén's depth and location "West Indies" being rather inaccurate).

Category A comprises the great majority of all occurrences of this species in less than 100 fathoms. Category C and D zoaria on the other hand were not found in less than 196 fathoms. This strongly suggests that, although the larvae may operate and settle in neritic depth, conditions on the continental shelf are really unfavourable to adult growth.

The not uncommon occurrence of incrusting zoaria (category A *p.p.*, B) has led me to examine Silén's interpretation of the zoarial growth habit in the living *Fedora nodosa* more critically. The semi-ovoid or egg-shaped (category C and D) colonies of this species are considered by Silén (*l.c.*, p. 27 and text-fig. 43) to be "internodes connected by chitinous tubes (transformed zoids) to nodose branches that emanate from the encrusting original part of the zoarium with the ancestrula". The question whether these nodose branches were standing upright on or hanging downwards from the supporting medium was left undecided (*l.c.*, p. 28). As the nature of these chitinous tubes has a direct bearing on the problem, it is necessary to quote Silén in full on this point (*l.c.*, p. 13): "In the material of *Fedora nodosa* n. sp. (p. 53) there occurs a zoarium from which a strong tube extends at the point from which the zoid rows of the zoarial body emanate (text-fig. 41, pl. 4, fig. 22). This is a tube of a structure quite different from those of the Conescharellinidae. It is stiff, its chitinous walls are comparatively thick and are, so to speak, undulated. It widens considerably towards the end that is directed from the zoarium. All these features point to the mode of life of this zoarium being as follows. It is fixed to some substratum by the tube and stands stiffly out from that substratum. A short (broken) tube of the same structure emanates in the same way from one of the remaining 12 zoaria of this species; the others are without these appendages. (All the zoaria are dry, cf. p. 14.) From the opposite end of this second zoarium there emanates a short (broken) tube of the same structure but thinner (text-fig. 42). This fact shows that what has been called the zoarium above is not the entire zoarium but only a pedunculate portion of it. When alive it was continued by a tube that led to another portion of probably the same appearance. Thus the living zoarium certainly had the structure schematically shown in text-fig. 43. It is even possible that several similar portions followed each other in a row, all of them connected by tubes of the structure described

above." Silén further stated (*l.c.*, p. 14): "These tubes, however, are of a different and more solid structure than those of the Conescharellinidae, and thus the possibilities for their preservation are greater. They are, however, fragile enough, as I found when I happened to break one of them though it was only very slightly touched".

In May 1956, during a visit to the U.S. National Museum, I had the opportunity to examine 17 topotype specimens of *F. nodosa* from Albatross Station D.2398, all of which had at least a few opercula still *in situ*. To my surprise no chitinous tubes occurred in these specimens, although in view of the frequent occurrence of other chitinous parts (*i.e.* the opercula), one would certainly have expected them to be present, if they really are an essential part of the colony.

My suspicion was further raised when I started to find chitinous tubes similar to those described by Silén attached to the zoaria of other species of Bryozoa in the collections of the Division of Invertebrate Paleontology, U.S. National Museum. In several dry zoaria of *Mamillopora cupula*, from Fowey Light, 15 mi S of Miami, 40 fathoms, for instance, one or more of the depressions on the inside of the cup are still covered by a brownish, very fragile, chitinous membrane. Canu and Bassler (1928a, p. 153) refer to these dorsal depressions in *M. tuberosa* and *M. cavernulosa* as "hydrostatic cavities". In the centre of this membrane a small, circular opening is preserved, and in the more complete preservation a brownish, very fragile, finely annulated and somewhat flaring, chitinous tube emerges from this pore, very similar though not quite as long as the tube connected to Silén's specimen of *F. nodosa* (*l.c.*, pl. 4, fig. 22). I have also observed these tubes on the concave side of specimens of *Cupuladria canariensis* from the same locality. In a few dry specimens of *Mamillopora cupula* from Albatross Station D.2639, 56 fathoms, Straits of Florida, similar brownish tubes were found attached to the convex side of the zoarium, directly emerging from the zooecial orifices. The longest tube measured in the latter specimens was approximately 5 mm and had gained considerably in diameter at its flaring end. The obvious conclusion from these observations was that the association bryozoan-chitinous tube is purely incidental, and that the tubes must form part of a different, sessile organism.

I have submitted the specimens discussed in the previous paragraph to the distinguished opinions of Dr. Marian Pettibone and Dr. Frederick M. Bayer of the Division of Marine Invertebrates, U.S. National Museum, and both suggested that the tubes probably represent the chitinous perisarc of a hydroid. This opened the possibility that the tubular attachments described in *F. nodosa* would also be of hydroid origin.

Later in 1956 Dr. Alfred R. Loeblich Jr., who had followed this development with keen interest, very obligingly sent me a selection of ovoid and semi-ovoid colonies from Albatross Station D.2399, 196 fathoms, located in the close vicinity of Albatross Station D.2398, and therefore from the type area of *F. nodosa*. Indeed, 24 zoaria appeared to belong to *F. nodosa* and among these there is a large and perfectly ovoid zoarium with a chitinous tube of slightly less than 3 mm attached to it. This tube is in all respects similar to the one described by Silén, except that its expanded base is not attached to the proximal "emanation-point" (*l.c.*, text-figs. 41, 44), but is sitting right on top of a zooecium in the proximal part of the colony. This specimen has been examined by Miss P. M. Ralph and Dr. W. J. Rees of the Department of Zoology of the British Museum (Natural History). Miss Ralph immediately recognised the chitinous tube as "the covering case (Hydrotheca) of the polyp of a Scyphomedusa." Dr. Rees not only expressed his desire to obtain

the specimen for the scyphozoan collection, but also tentatively identified the genus as "*Stephanoscyphus*?" This, I think, settles the issue.

The chitinous tubes no longer being instrumental in connecting the zoarium of *F. nodosa* with the substratum, one can only speculate as to an alternative mode of living. The tendency, observed in category B zoaria, of the larva to settle upon and of the colony partially or entirely to envelop small foreign objects strongly suggests an analogy with the zoarial growth of *Cupuladria*, *Discoporella* and *Lunulites*. The adult zoarium of *F. nodosa* would thus rest on the bottom with its (distal) growing edge and gradually raise itself above the sea floor with the blunt ancestrular region ("emanation-point") directed upward.

It is here, I believe, that a discussion of the "special chambers" is in order. "Special chambers" occur very persistently distally to the orifices in both *F. edwardsi* Jullien (the type species, by monotypy, of *Fedora* Julien, 1883 and spelled correctly on p. 529 of Jullien's paper) and in *F. nodosa* Silén, to which the following description applies. They are open in most cases and a small pore at the bottom leads into the interior of the zoarium. In the proximal, ancestrular part of the zoarium they are closed by a calcareous deposit, as described by Silén (*l.c.*, p. 55). Their formation is best seen by turning the distal side of a semi-ovoid or hemispherical colony upward, so as to expose the growing edge. They are then seen being formed as diamond-shaped concavities at the periphery of the zoarium, astride the distal crest of the zooecia, with the small pore situated in the angle nearest to the zoarial axis. As Silén (*l.c.*, p. 52) points out, Jullien (1883, p. 513) gave an accurate description of these structures in *F. edwardsi*, but it is now recognised that they are not reproductive organs. According to Silén (*l.c.*, p. 52), "its mode of formation shows that it is of zoidal nature, a dwarfed heterozoid."

In order to arrive at some conclusion about their possible function, the following observations must first be mentioned:

- 1) "special chambers" persistently occur distally to all zooecia in all colonies, even in juvenile zoaria with not more than three zooecia (Pl. VII, fig. 5). Conclusion: "special chambers" do have an absolutely essential function in the colony.
- 2) The closure of the "special chambers" by a calcareous deposit in the proximal, ancestrular part by the zoarium suggests that their presence is no longer needed in that part of the colony. Conclusion: their function is primarily required in the distal part of the zoarium.
- 3) Unlike the small distal chambers which accommodate the vibracular setae in *Cupuladria* and *Discoporella*, the "special chambers" in *F. nodosa* are perfectly symmetrical. Their opening is plain, without projecting structures which might serve for the articulation of the base of a vibracular seta.
- 4) One of the "special chambers" at the growing edge of a specimen of *F. nodosa* from Caroline 1933 Station 94 with the opercula still intact was found occupied by an elongate chitinous structure suggestive of a short anchoring filament or rootlet. Tentative conclusion: the "special chambers" are rootlet chambers.
- 5) In the adult hemispherical or semi-ovoid colonies the axes of the "special chambers" at the growing edge are located approximately in one single plane perpendicular to the zoarial axis.

Final working hypothesis: the special chambers give rise to a circle of radiating anchoring filaments or rootlets at the growing edge of the colony perpendicular to the

	Number of specimens and category to which they belong		
North-western Gulf:			
Vema-3 1954 Drag 6	2 A	30	fathoms
Univ. of Houston sample 12	1 A	31 $\frac{1}{3}$	fathoms
Cavalier 1956 Station 317	10 A	50	fathoms
Cavalier 1956 Station 316	5 A, 3 B	50	fathoms
Cavalier 1956 Station 311	1 A	70	fathoms
Cavalier 1956 Station 309	4 A	57	fathoms
Cavalier 1956 Station 308	13 A	40	fathoms
Cavalier 1956 Station 307	3 A	35 $\frac{1}{2}$	fathoms
Cavalier 1956 Station 306	7 A	35	fathoms
Cacalier 1956 Station 278	18 A, 12 B	38	fathoms
Cavalier 1956 Station 225	1 A	50	fathoms
Cavalier 1956 Station 226	1 A	56	fathoms
Cavalier 1956 Station 227	8 A	37 $\frac{1}{2}$	fathoms
Cavalier 1956 Station 229	8 A	57	fathoms
Eastern Gulf:			
Sandpile Bank	21 A	49	fathoms
Hydrographer 1941/42 Station 50	1 frgt.	103.8	fathams
Albatross 1885 Station D.2398	17 C & D	227	fathoms
D.2399	24 C & D	196	fathoms
Albatross 1885 Station	7 frgts..	100	fathoms
Atlantis 1951 Station 153	3 A	80	fathoms
Atlantis 1951 Station 154	4 A, 2 B	64	fathoms
Atlantis 1951 Station 155	9 A	43	fathoms
Atlantis 1951 Station 156	2 A	32	fathoms

Atlantis 1951 Station 157	14 A	34	fathoms
Atlantis 1951 Station 158	5 A	33	fathoms
Atlantis 1951 Station 159	2 A	28	fathoms
Atlantis 1951 Station 160	1 A	25	fathoms
Atlantis 1951 Station 161	19 A	22	fathoms
Vema-3 1954 Dredge #1	4 A	117	fathoms
Vema-3 1954 BT #2			
Vema-3 1954 Dredge #2			
Florida Straits:			
off Molasses Reef Light	15 B	122	fathoms
	1 A, 1 B	120	fathoms
E of Triumph Reef	3 A	45	fathoms

Additional occurrence

N of Puerto Rico and the Virgin Islands			
Caroline 1933 Station 9	7 C & D	240	fathoms
Caroline 1933 Station 9	10 C & D	400	fathoms
Caroline 1933 Station 94	1 B		

Fossil Occurrence

Pleistocene ("Upper Marine") of Mississippi River Delta, South Pass Block 6 Area, State Lease 2590 #1, in ditch cuttings from the interval 500–1100', 12 A & B.

Distribution

E Gulf of Mexico Albatross 1885 Station D.2398, SSE of Fort Pickens, Florida, 227 fathoms.

Family TUBULIPORIDAE JOHNSTON, 1838

Genus *Stomatopora* Bronn, 1825*Stomatopora trahens* (Couch)

(Pl. VIII, fig. 6)

Non Alecto granulata Milne-Edwards (1838, p. 205, pl. 16, figs. 13, 13a).

Alecto granulata Johnston (1847, p. 280, pl. 49, figs. 1, 2), Busk (1975, p. 24), Busk (1886, p. 22).

Tubulipora trahens Couch (1841, p. 71), Couch (1844, p. 105, pl. 19, fig. 5, *non* fig. 3, *fide* Gregory, 1896, p. 48, footnote).

Stomatopora granulata (Milne-Edwards) Hincks (1880a, p. 425, pl. 57, figs. 1, 2), Norman (1909, p. 278), O'Donoghue and O'Donoghue (1926, p. 17), Borg (1926, p. 359, text-figs. 67, 68), Marcus (1940, p. 52, text-fig. 26), Osburn (1953, p. 619, pl. 65, figs. 1, 2).

Stomatopora granulata Hincks: O'Donoghue and O'Donoghue (1923, p. 11).

Material

Locality 55(1).

Remarks

Alecto granulata Milne-Edwards is the name of a Cretaceous fossil from the "grès vert inférieur" of Vassy, Haute-Marne, France. The identification of the Recent form com-

monly labelled *Stomatopora granulata* (Milne-Edwards) with the Cretaceous fossil formally entitled to that name is open to serious doubt. It does seem rather improbable that a species, in the Linnean sense, would attain a life-span of some 100 million years. Besides, there are a number of morphological differences, as Gregory (1896, p. 47; 1899, p. 7) has shown. Nevertheless, the practice of using Milne-Edwards's name for the Recent form has persisted into modern literature. I have here followed a suggestion by Gregory (1896, p. 48; 1899, p. 7), who proposed to distinguish the Recent species as *Stomatopora trahens* (Couch).

It is interesting to observe how the pattern of growth in the dichotomising *Stomatopora*, striving to cover the largest possible area of the available substratum, anticipates an imminent contact between the zooecia of neighbouring branches. For, as Canu and Bassler (1920, p. 654) have observed, "the branches of the same zoarium of *Stomatopora* . . . never grow over each other . . . ; a branch is arrested in growth when it encounters another."

A first step (A) towards the avoidance of such a lateral contact is the progressive reduction of the angle of branching in the second and later dichotomies (Lang, 1904, p. 319). A further measure (B) to this end is the skipping of dichotomies. In *Stomatopora trahens* each zooecium usually leads into a distal dichotomy. But there are some zooecia which produce only one distal zooecium, the branch thus continuing in a straight line in order to find more "elbow-room" for the next bifurcation.

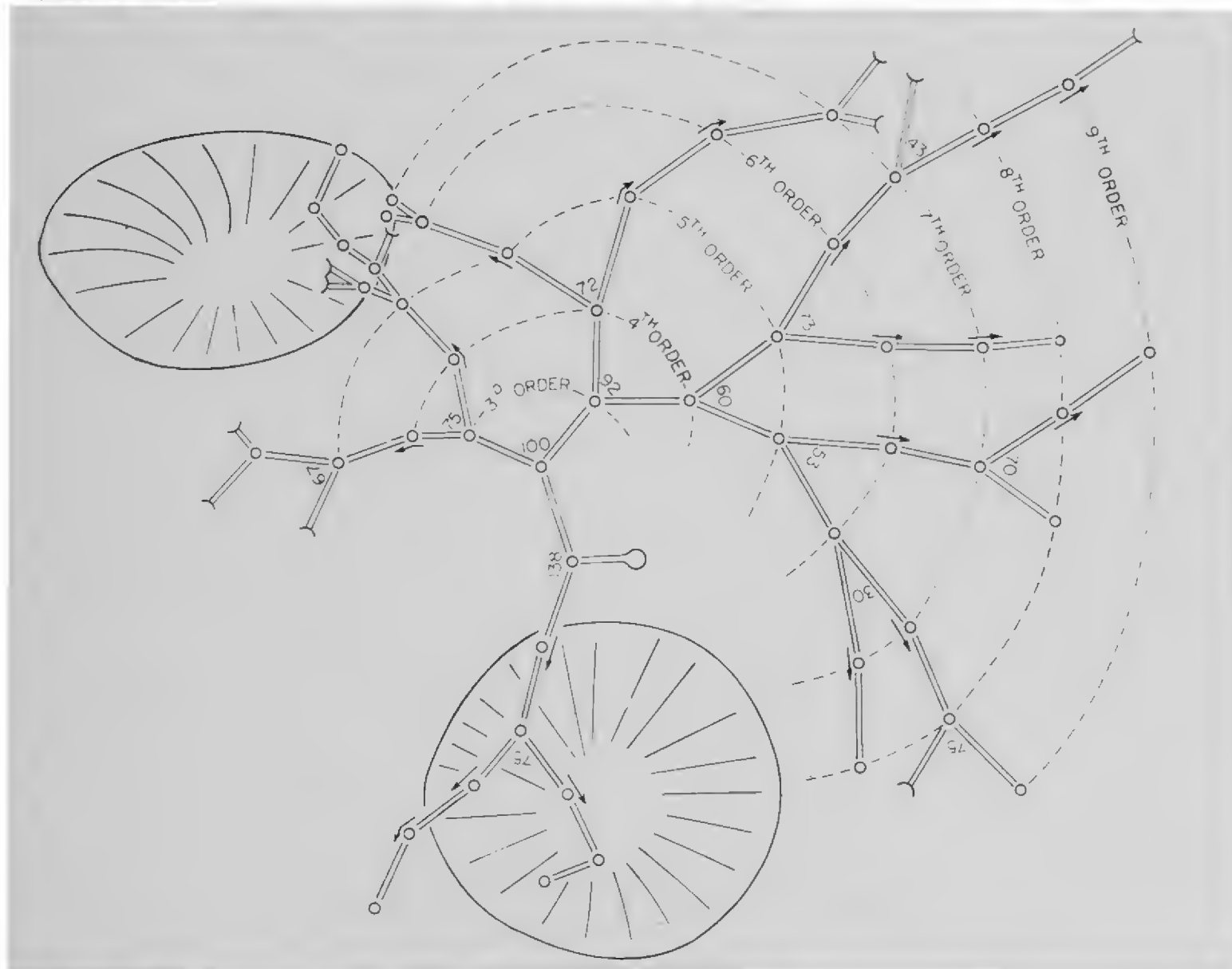


FIG. 4. Diagram of growth pattern observed in specimen of *Stomatopora trahens* (Couch). "Spoked wheels" represent calices of small branching coral which serves as substratum.

The angles of divergence at the various dichotomies in our single Gulf specimen are shown in text-fig. 4. Our observations on this large specimen suggest that—unless irregularities of the substratum dictate otherwise—the incidence of (*B*) is to some extent dependent on the progression of (*A*). Or, to put it more specifically: on a plain surface no dichotomies are skipped distally to a bifurcation with an angle of 90° and more. In our specimen values smaller than 90° are reached only at the third and later dichotomies. Therefore, skipping of dichotomies also occurs only after the third and later dichotomies. It is also observed that the very small angles (30–43°), which are found at some bifurcations of the sixth and higher order, invariably give rise to skipped dichotomies.

Occurrence

North-western Gulf: Cavalier 1956 Station 39 81½ fathoms

Distribution

E Atlantic from Spitzbergen to the Cape Verde Islands	
Mediterranean	
off Inaccessible Island, Tristan da Cunha	60–90 fathoms
Straits of Magellan	
off Santa Catalina Island, and	
off San Pedro, Southern California	45 fathoms
British Columbia	12–30 fathoms
Tizard Reef, China Sea	

Family CRISIIDAE JOHNSTON, 1838

Genus *Crisulipora* Robertson, 1910

Crisulipora occidentalis Robertson

(Pl. VII, fig. 6)

Crisulipora occidentalis Robertson (1910, p. 254, pl. 21, figs. 22, 23, 24), Okada (1917, p. 342), Marcus (1937, p. 21, pl. 3, fig. 5), Osburn (1953, p. 686, pl. 72, fig. 6), Lagaaij (1959, p. 484, text-fig. 5).

Crisia sp. Canu and Bassler (1928a, p. 157, pl. 30, figs. 1, 2).

Material

Locality 2(1), 55(4), 69(3), 70(1), 71(2), 72(1), 74(23), 77(3), 88(29), 89(2), 94(11), 99(2), 100(1), 101(3), 102(9), 103(32), 104(3), 111(25), 145(3), 150(105), 179(14), 180(1), 181(2), 353(3), 379(23), 380(34), 381(18), 382(49), 383(50), 384(12), 385(13), 386(62), 387(97), 388(22), 389(37), 390(67), 391(5), 392(4), 394(12), 395(17), 396(4), 414(2), 416(14), 418(1), 419(1), 443(9), 444 (numerous), 457(3).

Remarks

This form has previously been recorded from the Gulf of Mexico under a different name. After examining the specimen (U.S.N.M. Cat. No. 648060), I am convinced that the “curious fragment with white joints,” described and figured by Canu and Bassler (1928a) from Albatross Station D.2405, 30 fathoms, belongs here, rather than to *Crisia ramosa* Harmer as suggested by Osburn (1940, p. 329).

As in other jointed species, the dead colonies of *Crisulipora occidentalis* soon fall apart into their individual internodes. These isolated internodes, or parts thereof, accumulate freely on the bottom. This may partly explain the long list of occurrences here cited. Live specimens, with their internodes still connected by chitinous joints, were brought up at two of the forty-eight Gulf stations here listed: SSW of John's Pass, Florida, 34 fathoms, and Cavalier 1956 Station 322, 23 fathoms (Claypile Bank, specimens taken off large *Spondylus*).

Occurrence

North-western Gulf:

off Rio Grande	50 fathoms
Cavalier 1956 Station 39	81 $\frac{1}{3}$ fathoms
Vema-3 1954 Core #65	30 fathoms
Univ. of Houston sample 15	291 $\frac{1}{6}$ fathoms
Univ. of Houston sample 11	295 $\frac{5}{6}$ fathoms
Univ. of Houston sample 12	311 $\frac{1}{3}$ fathoms
Univ. of Houston sample 5	31 fathoms
Heald Bank	101 $\frac{1}{2}$ fathoms
Cavalier 1956 Station 322	23 fathoms
Cavalier 1956 Station 321	271 $\frac{1}{2}$ fathoms
Cavalier 1956 Station 316	50 fathoms
Cavalier 1956 Station 311	70 fathoms
Cavalier 1956 Station 310	60 fathoms
Cavalier 1956 Station 309	57 fathoms
Cavalier 1956 Station 308	40 fathoms
Cavalier 1956 Station 307	351 $\frac{1}{2}$ fathoms
Cavalier 1956 Station 306	35 fathoms
Cavalier 1956 Station 299	111 $\frac{1}{6}$ fathoms
Cavalier 1956 Station 273	24 fathoms
Cavalier 1956 Station 278	38 fathoms
Cavalier 1956 Station 227	371 $\frac{1}{2}$ fathoms
Cavalier 1956 Station 228	271 $\frac{1}{2}$ fathoms
Cavalier 1956 Station 229	57 fathoms

Eastern Gulf:

off Choctawhatchee Bay	151 $\frac{1}{3}$ fathoms
off Cedar Keys	8-64 fathoms
off Egmont Key	8-111 $\frac{1}{2}$ fathoms
Vema-3 1954 Dredge #2	29 fathoms
SSW of John's Pass, Florida	34 fathoms
Florida Straits:	
S of Sombrero Key	25 fathoms

Additional occurrence

Specimen, labelled "*Crisulipora*" (U.S.N.M. Cat. No. 9739), from Albatross Station D.2411, Gulf of Mexico, 27 fathoms

Distribution

Gulf of Mexico	30 fathoms
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Bay of Santos, Brazil	20 metres
American Pacific coast from Point Conception, California to the Lobos de Afuera Islands, Peru	0-47 fathoms
Bay of Sagami, Japan	

Fossil distribution

Upper Middle Miocene of Bowden, Jamaica, B.W.I.

Family TUBULIPORIDAE JOHNSTON, 1838

Genus *Idmidronea* Canu 1919

Idmidronea flexuosa (De Pourtales)

(Pl. VII, fig. 7)

Idmonea flexuosa De Pourtales (1867, p. 111).

Tubulipora flexuosa Osburn (1953, p. 653, pl. 71, fig. 11, *cum syn.*).

Material

Locality 412(1), 458(10), 458a(3), 469(1).

Remarks

The specimens taken off Molasses Reef Light have all gone through the process of alteration which has affected so many calcareous organisms in the deeper samples from the Florida Straits. They now appear as highly polished, brownish internal casts of the original system of hollow zooecial tubes. X-ray analysis of selected specimens of Bryozoa in this condition, made at the E & P Research Laboratory of Shell Development Company, Houston, Texas, indicate an aragonite content of only 23-30%, versus 70-77% calcite. Yet two characters remain which permit identification: 1) the slender, often somewhat curved, zoarial branches; 2) the occurrence in each fascicule of not more than two zooecia.

The single Oregon specimen, on the other hand, is extremely well preserved, with the strongly produced peristomes in each fascicule adnate over their entire length (Pl. VII, fig. 7).

Occurrence

Eastern Gulf: Vema-3 1954 Station BT #2	96 fathoms
Florida Straits: off Molasses Reef Light	120-122 fathoms
NW of Cay Sal Bank	150 fathoms

American distribution

off Havana, Cuba	270 fathoms
Cape le Vela, Colombia	22-41 fathoms
Gulf of Venezuela	
Aruba	
Tortuga Island	
Raza Island, Gulf of California	40 fathoms
James Island, Galapagos	54 fathoms

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¹ Date unknown, but of no consequence, as all the corresponding specific names were issued by Audouin in 1826.

APPENDIX

List of localities

Locality number	Lat. N	Long. W	Depth in fms	Various collecting details
2	25°47'	96°27'	50	
4	Corpus Christi Bay		2½	Coll. by Messrs. E. A. Lohse & W. A. Price, June 1956
5	Corpus Christi Bay		5½	Coll. by Messrs. E. A. Lohse & W. A. Price, June 1956
10	Corpus Christi Bay		1½	Coll. by Messrs. E. A. Lohse & W. A. Price, June 1956
13	St. Joseph Island, near Aransas Pass		beach	Coll. by Mr. H. Odé, March 1957
14	Mud Is., Aransas Bay		5½-1	Coll. by Mr. Donald Moore, 29th June 1954
16	28°50' 5"	95°23'53"	4	Cavalier 1956 Station 15
23	28°43'18"	95°19' 9"	8½	Cavalier 1956 Station 12
26	28°52' 5"	95°19'42"	3½	Cavalier 1956 Station 5
28	due E of Freeport		beach	Coll. by Dr. H. A. Bernard, 20th March 1956
31	28°53'16"	95°15'30"	6½	Cavalier 1956 Station 2

List of localities (continued)

Locality number	Lat. N	Long. W	Depth in fms	Various collecting details
36	28°47'30"	95°15'24"	9 $\frac{5}{8}$	Cavalier 1956 Station 20
55	28°50'36"	95° 8' 5"	8 $\frac{1}{3}$	Cavalier 1956 Station 39
60	Galveston Island, opposite Mud Island (San Luis Pass)		beach	Coll. by the author
61	Galveston Island, near San Luis Pass		beach	Coll. by the author
62	Galveston Island, 3 mi. SW of Stewart Rd.		beach	Coll. by Mr. H. Odé, 24th March 1957
63	Galveston Island		beach	Coll. by Mr. B. S. Parrott, November 1956
64	Galveston Island, near 8 Mile Road		beach	Coll. by Dr. H. A. Bernard, 12th December 1955
65	Galveston Island, at Galveston		beach	Coll. by Mr. H. Odé, 31st December 1956
67	28°40'	94°33'	15	Coll. by University of Houston students, samples no. 1-4 (see Kellough, 1956)
68	28°10'42"	94°15'	30	Vema-3 1954 Drag 6 and Core #65 (top 0-12") (see Ewing and Ericson, 1954)
69	Vicinity of Stetson Bank		approx. 30	Anchor sample, don. by Mr. S. J. Rosenfeld
70	28° 9'53"	94°17'52"	29 $\frac{1}{8}$	Coll. by University of Houston students, sample no. 15 (see Kellough, 1956)
71	28° 9'34"	94°17'26"	29 $\frac{5}{8}$	Coll. by University of Houston students, sample no. 11 (see Kellough, 1956)
72	28° 9'18"	94°17' 4"	31 $\frac{1}{3}$	Coll. by University of Houston students, sample no. 12 (see Kellough, 1956)
74	28°11'22"	94°15'30"	31	Coll. by University of Houston students, sample no. 5 (see Kellough, 1956)
76	Heald Bank		8 $\frac{1}{3}$	Dredge sample
77	29° 4'	94°14'	10 $\frac{1}{2}$	
78	29° 3'15"	94°18'45"	6 $\frac{2}{3}$	Cavalier 1956 Station 331
80	28°58'45"	94°18'45"	6	Cavalier 1956 Station 329
86	28°33'	94°12'15"	20	Cavalier 1956 Station 324
88	28°20'	94° 9'	23	Cavalier 1956 Station 322
89	28°17'30"	94° 8'30"	27 $\frac{1}{2}$	Cavalier 1956 Station 321
93	27°58'45"	93°49'45"	50	Cavalier 1956 Station 317
94	27°54'15"	93°47'45"	50	Cavalier 1956 Station 316
95	27°48'45"	93°45'30"	92	Cavalier 1956 Station 315
97	27°41'	93°42'15"	200	Cavalier 1956 Station 313
99	27°51'30"	93°47'	70	Cavalier 1956 Station 311
100	27°53'45"	93°46'30"	60	Cavalier 1956 Station 310
101	27°56'15"	93°46'	57	Cavalier 1956 Station 309
102	28° 4'	93°44'20"	40	Cavalier 1956 Station 308
103	28° 9'30"	93°43'15"	35 $\frac{1}{2}$	Cavalier 1956 Station 307
104	28°16'15"	93°42'15"	35	Cavalier 1956 Station 306
108	28°43'	93°34'45"	15	Cavalier 1956 Station 302
109	28°49'	93°33'15"	12 $\frac{1}{3}$	Cavalier 1956 Station 301
110	28°52'30"	93°32'	11	Cavalier 1956 Station 300
111	28°59'15"	93°30'15"	11 $\frac{1}{6}$	Cavalier 1956 Station 299
113	29°11'30"	93°26'	9	Cavalier 1956 Station 297
115	29°19'20"	93°36'30"	7	
119	29°24'42"	93°20'	7	Cavalier 1956 Station 292
120	29°26'24"	93°19'55"	4	Cavalier 1956 Station 291
126	29°27'	92° 4'30"	2	
132	29°11'48"	91°36'	3 $\frac{2}{3}$	Cavalier 1956 Station 259
145	28°31'30"	91°49'15"	24	Cavalier 1956 Station 273
150	28° 5'15"	91°58'	38	Cavalier 1956 Station 278
177	28°10'30"	91° 1'	50	Cavalier 1956 Station 225
178	28° 8'30"	91° 1'	56	Cavalier 1956 Station 226
179	28° 6'30"	91° 1'	37 $\frac{1}{2}$	Cavalier 1956 Station 227
180	28° 5'	91° 1'	27 $\frac{1}{2}$	Cavalier 1956 Station 228
181	28° 4'	91° 1'	57	Cavalier 1956 Station 229
193	28° 7'30"	90°13'30"	100	Cavalier 1956 Station 176
226	Grand Isle, Louisiana		beach	Coll. by Mr. B. S. Parrott
332	29° 4'24"	88°43'	49	Nautilus Station
349	28°32'	88° 6'	1181	Albatross 1885 Station 2383 (see Townsend, 1901)
351	29°46'30"	86°58'	103.8	Hydrographer 1941/42 Station 50 (see Lowman, 1949)

List of localities (continued)

Locality number	Lat. N	Long. W	Depth in fms	Various collecting details
353	30°15'	86°11'	15 $\frac{1}{3}$	Hydrographer 1941/42 Station 40 (see Lowman, 1949)
354	30°13'	86° 8'	12 $\frac{1}{2}$	Hydrographer 1941/42 Station 39 (see Lowman, 1949)
356	30° 5'58"	85°45'39"		Coll. by Mr. Donald Moore, August, 1954
357	30° 5'20"	85°46'32"		Coll. by Mr. Donald Moore, August, 1954
358	30° 4'40"	85°47'25"		Coll. by Mr. Donald Moore, August, 1954
359	30° 4'	85°48'16"		Coll. by Mr. Donald Moore, August, 1954
360	30° 3'20"	85°49'10"		Coll. by Mr. Donald Moore, August, 1954
361	30° 2'42"	85°50' 3"		Coll. by Mr. Donald Moore, August, 1954
363	30° 1'24"	85°51'54"		Coll. by Mr. Donald Moore, August, 1954
365	30° 6"	85°53'40"		Coll. by Mr. Donald Moore, August, 1954
367	29°33'	86° 8'	21 $\frac{1}{3}$	Hydrographer 1941/42 Station 45 (see Lowman, 1949)
368	28°45'	86°26'	227	Albatross 1885 Station 2398 (see Townsend, 1901)
369	28°44'	86°18'	196	Albatross 1885 Station 2399 (see Townsend, 1901)
377	28° 9'	85° 7'	100	Atlantis 1951 Station 152
378	28°11'30"	85° 2'	80	Atlantis 1951 Station 153
379	28°14'	84°57'	64	Atlantis 1951 Station 154
380	28°16'30"	84°52'	43	Atlantis 1951 Station 155
381	28°19'	84°46'30"	32	Atlantis 1951 Station 156
382	28°22'	84°41'	34	Atlantis 1951 Station 157
383	28°24'30"	84°36'	33	Atlantis 1951 Station 158
384	28°27'	84°31'	28	Atlantis 1951 Station 159
385	28°30'	84°25'30"	25	Atlantis 1951 Station 160
386	28°32'	84°20'	22	Atlantis 1951 Station 161
387	28°35'	84°14'	20	Atlantis 1951 Station 162
388	28°38'	84° 8'	20	Atlantis 1951 Station 163
389	28°41'	84° 2'	17	Atlantis 1951 Station 164
390	28°43'30"	83°56'	17	Atlantis 1951 Station 165
391	28°46'	83°50'	16	Atlantis 1951 Station 166
392	28°49'	83°44'	14	Atlantis 1951 Station 167
393	28°51'30"	83°39'30"	12	Atlantis 1951 Station 168
394	28°54'	83°34'30"	11 $\frac{1}{2}$	Atlantis 1951 Station 169
395	28°55'	83°28'30"	11	Atlantis 1951 Station 170
396	28°56'30"	83°22'	8	Atlantis 1951 Station 171
399	28°58'48"	83°16'42"	5 $\frac{1}{2}$	Coll. by Mr. Donald Moore, August 1954
401	29° 1'24"	83°13'20"	4 $\frac{1}{3}$	Coll. by Mr. Donald Moore, August 1954
403	29° 3'55"	83° 9'50"	3 $\frac{2}{3}$	Coll. by Mr. Donald Moore, August 1954
411	25°50'	84°30'	117	Vema-3 1954 Dredge #1
412	26°10'	84°20'	96	Vema-3 1954 BT #2
413	27°36'27"	83°11'	12 $\frac{1}{6}$	Coll. by Mr. Donald Moore, August 1954
414	27°36'27"	83° 8'57"	11 $\frac{1}{3}$	Coll. by Mr. Donald Moore, August 1954
415	27°36'27"	83° 6'52"	10 $\frac{1}{2}$	Coll. by Mr. Donald Moore, August 1954
416	27°36'27"	83° 4'48"	10 $\frac{2}{3}$	Coll. by Mr. Donald Moore, August 1954
417	27°36'27"	83° 2'42"	8 $\frac{2}{3}$	Coll. by Mr. Donald Moore, August 1954
418	27°36'27"	83° 30"	8 $\frac{1}{6}$	Coll. by Mr. Donald Moore, August 1954
419	27°36'27"	82°58'18"	8	Coll. by Mr. Donald Moore, August 1954
420	27°36'27"	82°56' 6"	7 $\frac{1}{6}$	Coll. by Mr. Donald Moore, August 1954
422	27°36'27"	82°51'42"	5 $\frac{1}{2}$	Coll. by Mr. Donald Moore, August 1954
424	27°36'45"	82°47'18"	6 $\frac{2}{3}$	Coll. by Mr. Donald Moore, August 1954
426	27°36'16"	82°43'18"	7	Coll. by Mr. Donald Moore, August 1954
427	27°36'44"	82°41'18"	6 $\frac{1}{6}$	Coll. by Mr. Donald Moore, August 1954
428	27°37' 8"	82°39'20"	6	Coll. by Mr. Donald Moore, August 1954
429	27°38' 9"	82°37'27"	4 $\frac{2}{3}$	Coll. by Mr. Donald Moore, August 1954
430	27°39'54"	82°36' 6"	5 $\frac{5}{6}$	Coll. by Mr. Donald Moore, August 1954
431	27°41'14"	82°34'43"	4 $\frac{1}{2}$	Coll. by Mr. Donald Moore, August 1954
432	27°42' 8"	82°33'36"	2 $\frac{1}{3}$	Coll. by Mr. Donald Moore, August 1954
434	27°44'51"	82°31'54"	4	Coll. by Mr. Donald Moore, August 1954
442	27° 8'	83°30'	23	Vema-3 1954 BT #2 (Top of core)
443	26°50'	83°40'	29	Vema-3 1954 Dredge #2
444	26°25'	83°32'	34	Coll. by Mr. Dan Steger
457	24°35'30"	81° 6'55"	25	Coll. by Dr. R. N. Ginsburg (see Ginsburg, 1956)
458	24°54'	80°15'30"	122	Coll. by Dr. G. L. Voss, 9th July 1950
458a	24°54'	80°15'30"	120	Coll. by Dr. G. L. Voss, 9th July 1950
461	25°13'15"	80° 7'	78	Coll. by Dr. G. L. Voss, 9th July 1950
464	25°28'30"	80° 5'45"	45	Coll. by Dr. R. N. Ginsburg (see Ginsburg, 1956)
465	25°28'30"	80° 5'	58	Coll. by Dr. R. N. Ginsburg (see Ginsburg, 1956)
469	24° 3'	80°30'	150	Oregon 1955 Station NW of Cay Sal Bank, 18th July 1955

List of Genera and Species

- acadiana, Phoceana
 Acanthodesia
 Aetea
 Alecto
 americana, Hippodiplosia
 americana, Lepralia
 ampla, Figularia
 anguina, Aeta
 anguina, Sertularia
 Antropora
 Arthropoma
 asper, Gemelliporella
 aspera, Gemelliporella

 Beania
 bellula, Bellulopora
 bellula, Colletosia
 bellua, Electra
 bellula, Membranipora
 bernardi, Hippopodina
 bicornis, Electra bellula var.
 Biflustra
 boryi, Caberea
 Boryi, Crisia
 brongniartii, Chorisopora
 brongniartii, Flustra
 Bugula

 Caberea
 californica, Chaperia
 canariensis, Cupuladria
 Canua
 caribbea, Vibracellina
 cavalieri, Euginoma
 cavernulosa, Mamillopora
 cecilii, Arthropoma
 cecilii, Flustra
 cervicornis, Chaperia
 Chaperia
 Chapperia
 Chorisopora
 Cleidochasma
 Codonellina
 Colletosia
 columnaris, Phoceana
 commensale, Conopeum
 Conopeum
 constricta, Setosellina
 contracta, Cleidochasma
 contracta, Hippoporina
 contracta, Lepralia
 contracta, Perigastrella
 contraria, Figularia
 cornuta, Arthropoma
 Crepidacantha
 Cribellopora
 cribriformis, Codonellina
 Cribrilaria
 Crisia
 Crisulipora
 crustulenta, Electra
 crustulenta var. arctica, Electra
 Cryptosula
 cupula, Mamillopora
 Cupuladria

 Dacryonella
 diaphana, Halysis
 diaphana, Scruparia

 Discoporella
 divae, Monoporella

 edwardsi, Fedora
 Electra
 elegans, Catenicella
 elegans, Vittaticella
 Eschara
 Escharina
 Euginoma
 Exochella

 Fedora
 Fedorella
 Figularia
 flabellata, Membranipora
 flexuosa, Idmonea
 flexuosa, Tubulipora
 Floridina
 Flustra
 fusca, Membranipora

 galeata, Chaperia
 Gemellipora
 Gemelliporella
 Gemelliporina
 glabra, Gemelliporella
 goësi, Heliiodoma
 goësi, Setosellina
 gorgonensis, Hippoporella
 granulata, Alecto
 granulata, Stomatopora

 Hagenowinella
 Halysis
 harmeri, Scrupocellaria
 hastingssae, Electra
 Heliiodoma
 hilli, Figularia
 Hincksina
 Hippodiplosia
 Hippoporella
 Hippoporina
 Hippothoa
 hirtissima, Beania
 horsti, Lacerna
 horsti, Schizopodrella
 horsti, Schizoporella
 horstii, Lacerna

 Idmonea
 isabelleana, Hippothoa

 Lacerna
 'Lagenipora'
 latirostris, Parellisina
 laxibasis, Vibracellina
 Lekythopora
 Lepralia
 longicollis, Lekythopora
 longirostris, Exochella
 longirostris, Mucronella
 Lunulites

 magellanica, Figularia
 Mamillopora
 marginata, 'Lagenipora'
 Membranipora
 Membrendoecium
 minima, Fedorella

Monoporella
monostachys, Electra
monostachys, Membranipora
montferrandii, Codonellina
montferrandii, Flustra
Mucronella
multicornis, Electra bellula var.

Nellia
neritina, Bugula
nodosa, Fedora

occidentalis, Crisulipora
oculata, Nellia

pallasiana, Cryptosula
Parasmittina
Parellisina
parvicella, Floridina
patagonica, Figularia
patula, Chaperia
patula, Chapperia
patula, Membranipora
pectoralis, Hippopodina
Perigastrella
periporosa, Hincksina
periporosa, Retevirgula
Phoceana
Pliophloea
poisonii, Crepidacantha
prolifera, Smittoidea
punctata, Gemellipora
Pyrulella

radiata, Colletosia
radiata, Eschara
ramosa, Crisia
Retevirgula
reticulata, Smittia
reticulata, Smittina
reticulata, Smittoidea
roulei, Setosellina

savartii, Acanthodesia
savartii, Biflustra
Schizopodrella
Schizolavella
Schizoporella
Scruparia
scrupea, Scrupocellaria

Scrupocellaria
serrata, Lepralia contracta var.
Setosella
Setosellina
signata, Parasmittina
signata, Smittia
signata, Smittina
simplex, Cribellopora
Smittia
Smittina
Smittoidea
solea, Crepidacantha
Stomatopora
strictorostri, Antropora
strictorostri, Membrendoecium

tenella, Electra
tenuis, Acanthodesia
tenuissima, Membranipora
teres, Crepidacantha poissonii var.
teres, Lepralia kirchenpaueri var.
trahens, Stomatopora
trahens, Tubulipora
trichotoma, Cribellopora
trichotoma, Schizopodrella
trichotoma, Schizoporella
tricuspis, Exochella
tricuspis, Mucronella
tuberculata, Membranipora
tuberosa, Mamillopora
tubigerum, Conopeum
tubulata, Retevirgula
Tubulipora
turrita, Bugula
typica, Canua
typica, Dacryonella

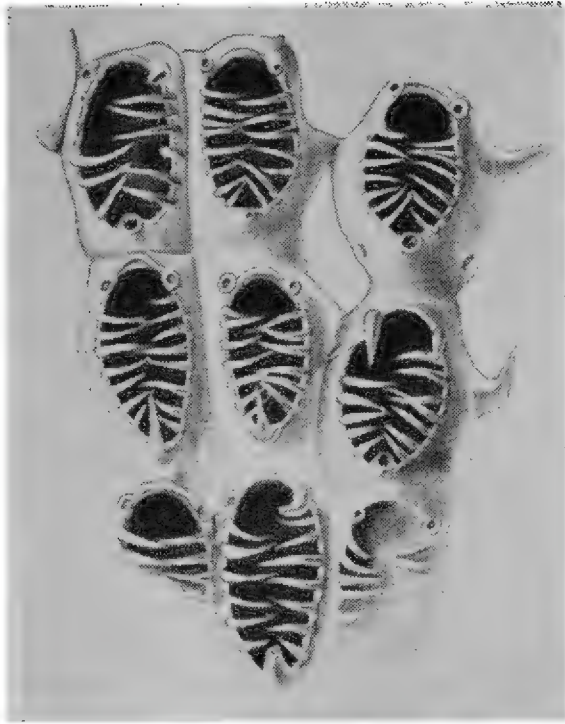
uberrima, Vittaticella
Umbonula
uvulifera, Lepralia

vermiformis, Euginoma
Vibracellina
Vittaticella
vulgaris, Eschara
vulgaris, Escharina
vulgaris, Schizolavella
vulgaris, Schizoporella
vulnerata, Membranipora
vulnerata, Setosella

PLATE I

Fig.

1. *Electra monostachys* (Busk). Station 61. USNM 64811. 40×
2. *Membranipora tenuissima* Canu. Station 226. USNM 648009. 40×
3. *Antropora typica* (Canu and Brassler). Station 379. USNM. 648012. 40×
4. *Retevirgula tubulata* (Hastings). Station 383. USNM 648014. 40×
- Basal surface with numerous peg-like processes.
5. *Retevirgula tubulata* (Hastings). Station 383. USNM 648015. 40×
- Fragment with ovicell.
6. *Retevirgula tubulata* (Hastings). Station 383. USNM. 648014. 40×
- Frontal surface of the same specimen as that shown in fig. 4.



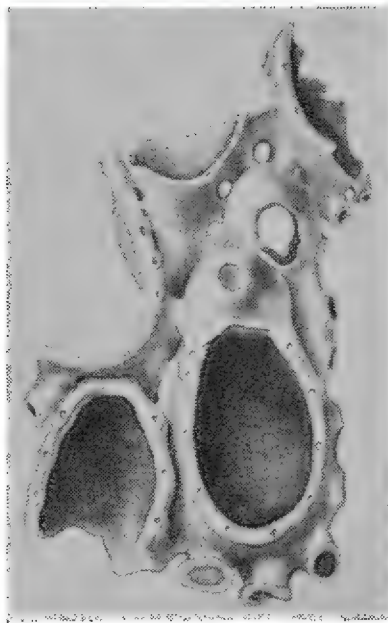
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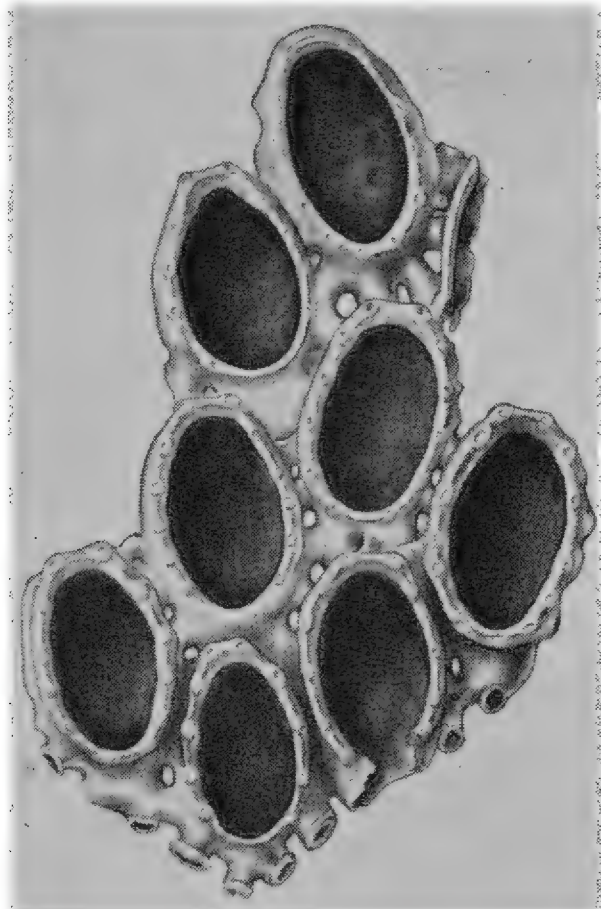
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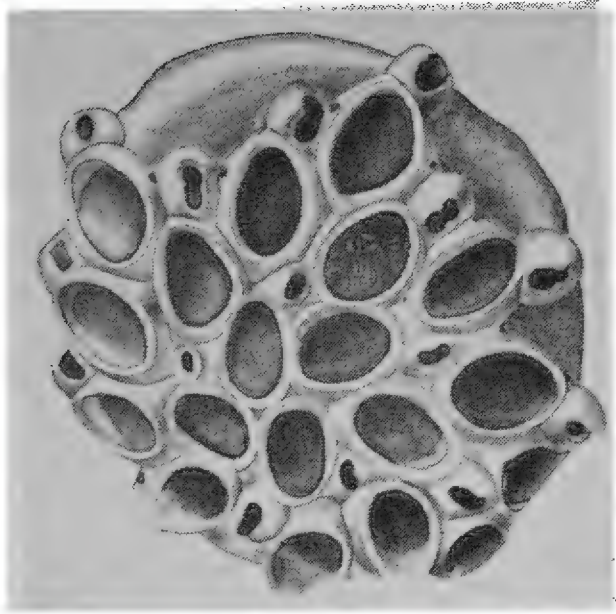


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PLATE II

Fig.

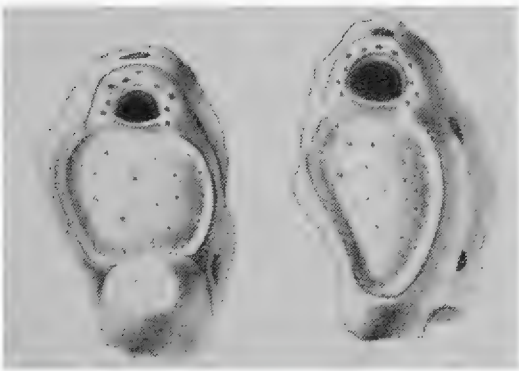
1. *Setosellina goësi* (Silén). Station 367. USNM 648013. 40×
2. *Chaperia patula* (Hincks). Station 412. USNM 648017. 20×
3. *Monoporella divae* Marcus. Station 179. USNM 648019. 40×
- Fragment with ovicell.
4. *Monoporella divae* Marcus. Station 179. USNM 648020. 40×
5. *Floridina parvicella* Canu and Bassler. Station 76. USNM 648018. 40×
6. *Euginoma cavalieri* sp. nov. Station 97. USNM 648022. 40×
- Holotype.
7. *Setosella vulnerata* (Busk). Station 458. USNM 648021. 40×



1

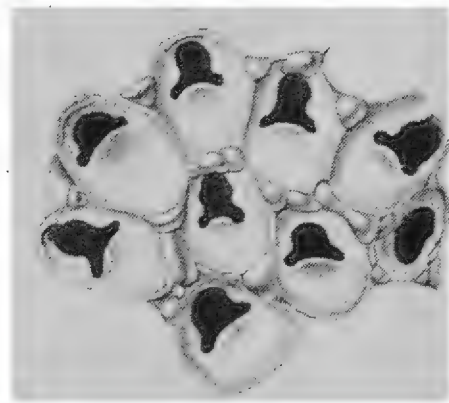


2



3

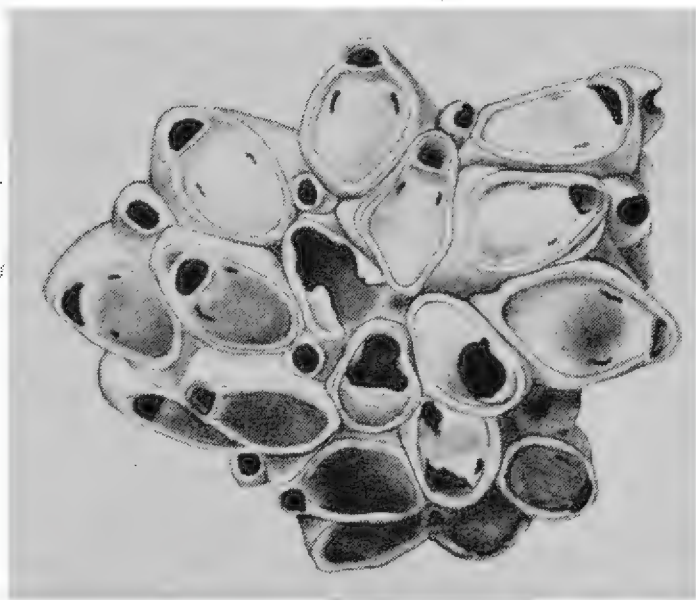
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PLATE III

Fig.

1. *Scrupocellaria harmeri* Osburn. Station 444. USNM 648025. 40×
Frontal view.
2. *Scrupocellaria harmeri* Osburn. Station 444. USNM 648025. 40×
Dorsal view.
3. *Caberea boryi* (Audouin). Station 444. USNM 648026. 40×
Frontal view.
4. *Caberea boryi* (Audouin). Station 444. USNM 648026. 40×
Dorsal view.



1



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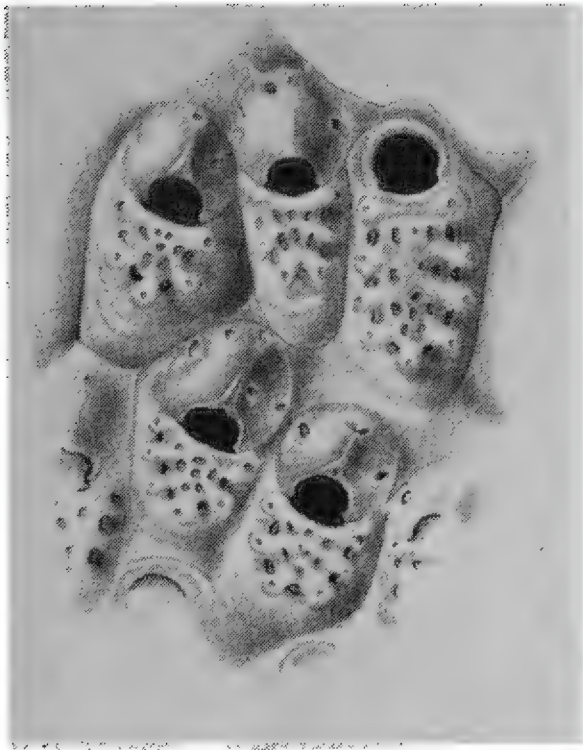


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PLATE IV

Fig.

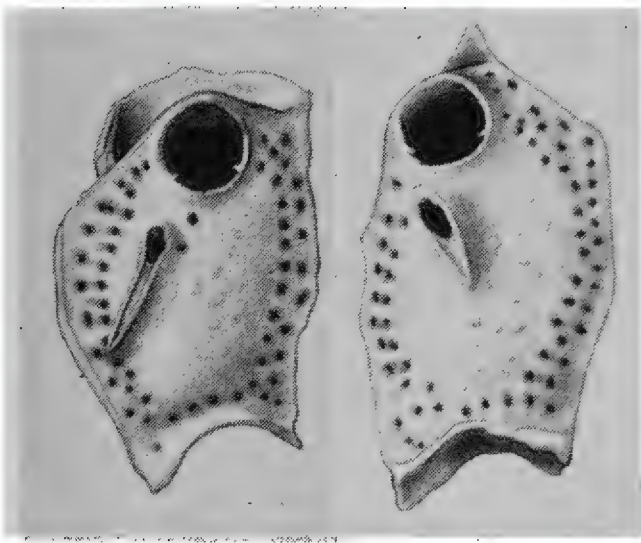
1. *Figularia contraria* sp. nov. Station 69. USNM 648027. 40×
Holotype.
2. *Bellulopora bellula* (Osburn). Station 179. USNM 648028. 40×
3. *Hippopodina bernardi* sp. nov. Station 99. USNM 648030. 40×
Holotype.
4. *Hippopodina bernardi* sp. nov. Station 99. USNM 648031. 40×
Paratype.
5. *Chorizopora brongniartii* (Audouin). Station 395. USNM 648029. 40×
6. *Arthropoma cecilii* (Audouin). Station 99. USNM 648033. 40×
7. *Cribellopora trichotoma* (Waters). Station 94. USNM 648034. 40×
8. *Cribellopora trichotoma* (Waters). Station 94. USNM 648035. 40×



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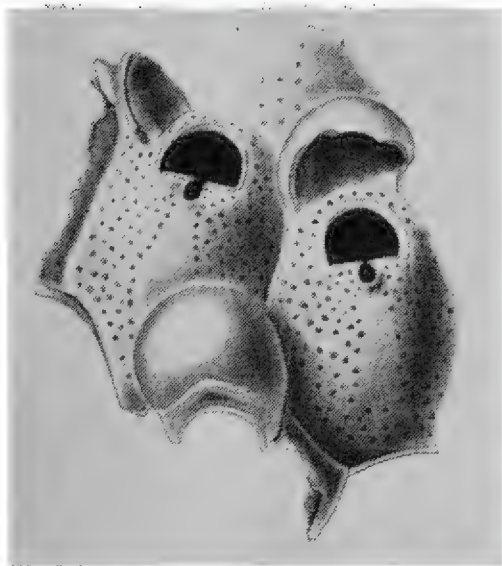


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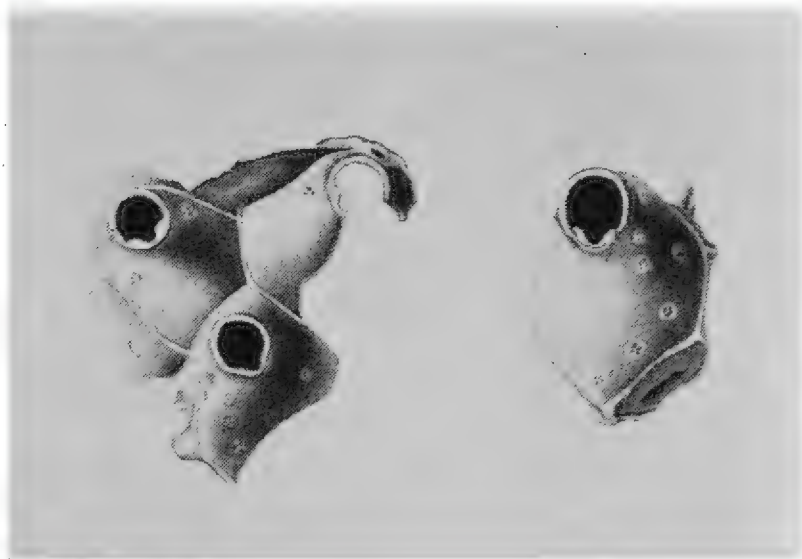
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PLATE V

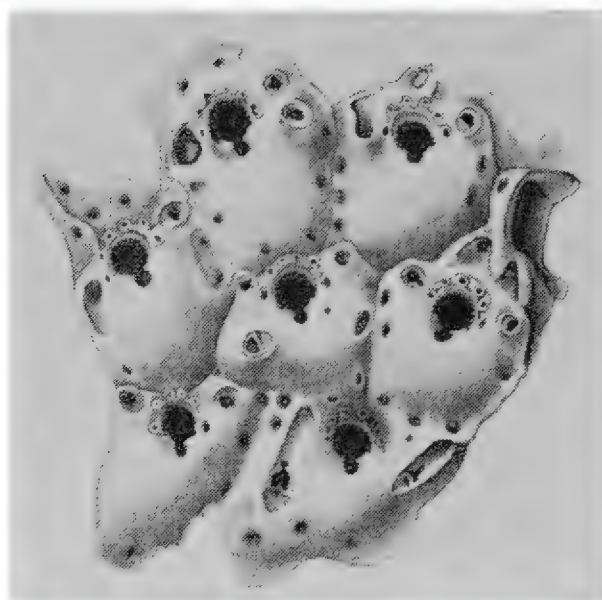
Fig.

1. *Escharina vulgaris* (Moll). Station 69. USNM 648036. 40×
2. *Cleidochasma contracta* (Waters). Station 99. USNM 648037. 40×
3. *Hippoporella gorgonensis* Hastings. Station 392. USNM 648038. 40×
4. *Hippodiplosia americana* (Verrill). Station 14. USNM 648039. 40×
5. *Exochella longirostris* Jullien. Station 99. USNM 648040. 40×

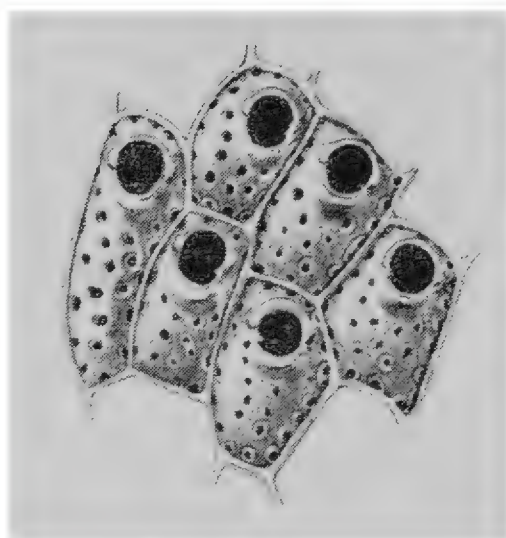
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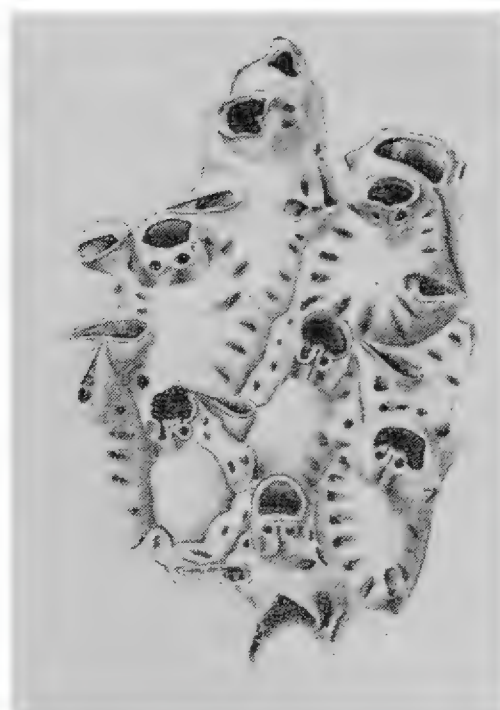


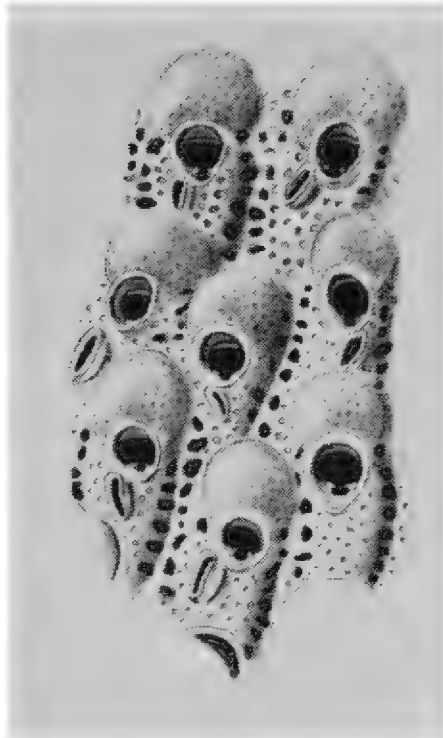
PLATE VI

Fig.

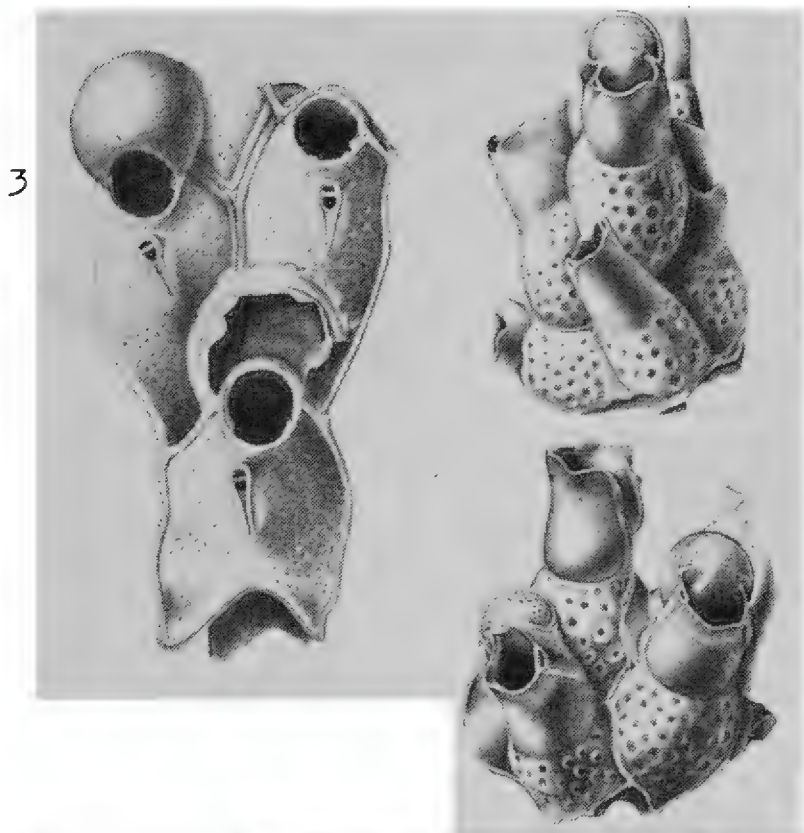
1. *Smittoidea reticulata* (Macgillivray). Station 99. USNM 648041. 40×
2. *Parasmittina signata* (Waters). Station 384. USNM 648043. 40×
3. *Codonellina montferrandii* (Audouin). Station 94. USNM 648042. 40×
4. *Lekythopora longicollis* sp. nov. Station 99. USNM 648048. 40×
- Holotype.
5. *Lekythopora longicollis* sp. nov. Station 99. USNM 648049. 40×
- Paratype.
6. *Crepidacantha poissonii* (Audouin). var. *teres* Hincks. Station 179.
(specimen lost) 40×
7. *Phoceana acadiana* sp. nov. Station 412. USNM 648045. 20×
- Paratype.



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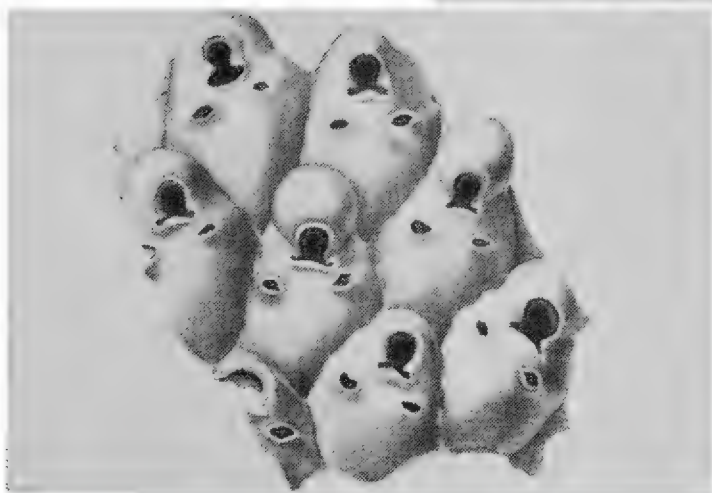
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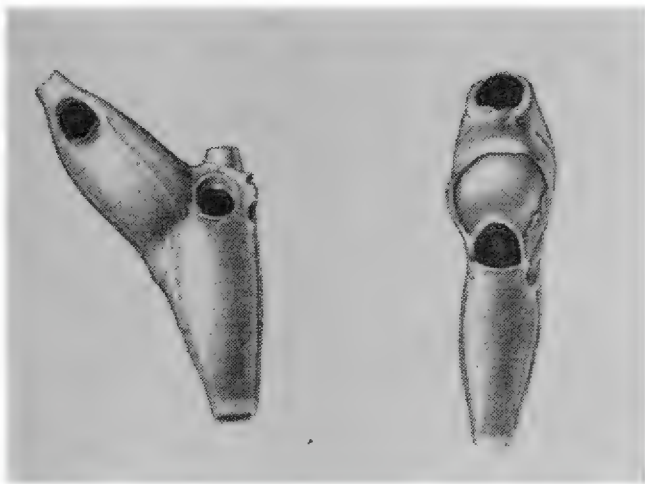


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PLATE VII

Fig.

1. *Vittaticella uberrima* Harmer. Station 111. USNM 648052. 40×
Ordinary biglobulus.
2. *Vittaticella uberrima* Harmer. Station 111. USNM 648053. 40×
Fertile biglobulus.
3. *Halysisis diaphana* (Busk). Station 390. USNM 648054. 40×
Fragment with broken ovicell.
4. *Fedora nodosa* Silén. Station 104. USNM 648055. 40×
Frontal view of juvenile specimen.
5. *Fedora nodosa* Silén. Station 104. USNM 648055. 40×
Distal view of the same specimen as that shown in fig. 4. The "special chambers"
are well exposed.
6. *Crisulipora occidentalis* Robertson. Station 443. USNM 648057. 20×
7. *Idmidronea flexuosa* (De Pourtales). Station 469. USNM 648058. 40×



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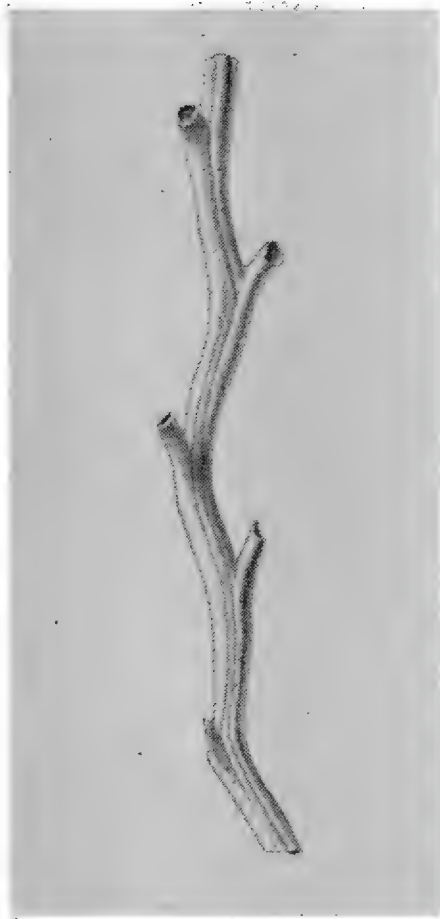


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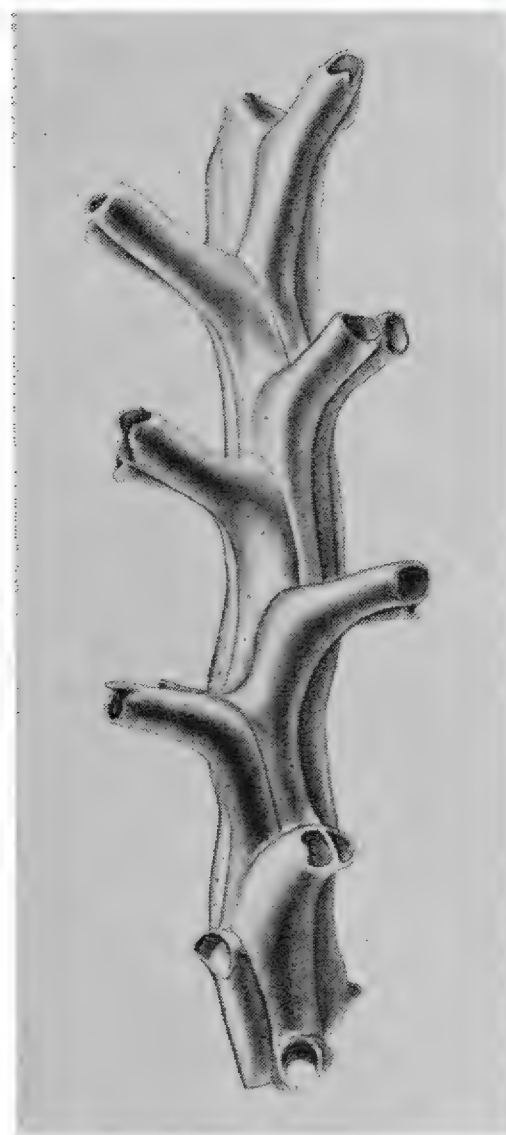


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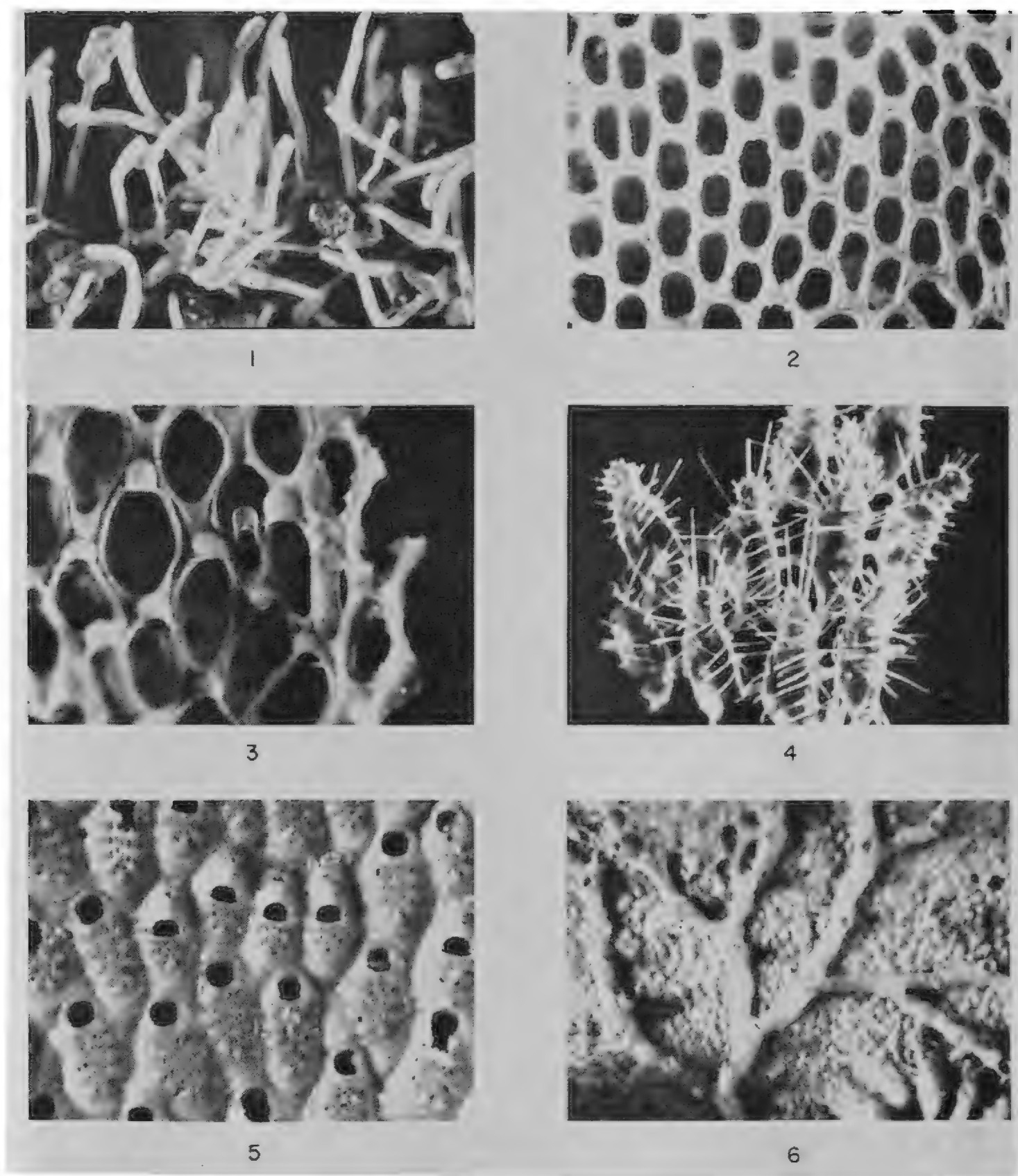


PLATE VIII

Fig.

1. *Aetia anguina* (Linnaeus). Station 64. USNM 648008. 24×
2. *Conopeum commensale* Kirkpatrick and Metzelaar. Galveston Island beach, Texas. USNM 648010. 24× The "brown lines" are clearly apparent. Two "rectangular blocs" are discernible in the fifth vertical row of zooecia from the right.
3. *Parellisina latirostris* Osburn. Station 69. USNM 648016. 24× Notice the characteristic avicularium and corresponding distal kenozoecium in centre of photograph.
4. *Beania hirtissima* (Heller). Station 444. USNM 648024. 24×
5. *Figularia contraria* sp. nov. Station 69. USNM 648027. 24× Holotype.
6. *Stomatopora trahens* (Couch). Station 55. USNM 648056. 24×

A Study of the Diatom Flora of Fresh Sediments of the South Texas Bays and Adjacent Waters¹

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Abstract

This paper gives a list, with illustrations and short descriptions, of the principal diatoms found in surface sediments of the Texas Bays from Port Isabel to Galveston. From annotations on occurrences in collections made in the summer of 1961 it will be seen that the synoptic diatom flora changes in some respects in the different bays and also differs from that of more easterly Gulf ports. Some 252 diatom species are listed, of which some appear to be new.

Introduction

The South Texas Bays form an almost continuous waterway from Port Isabel, close to the Mexican Border, to East Bay at Galveston. The bays are connected by the Intra-coastal Waterway, through which passes a great deal of small shipping. It might be expected that epontic species such as the *Amphoras* and *Cocconeis* might, in time, become distributed through the bays on the bottoms of ships and barges. In general, the environment consists of shallow bays, separated from the Gulf of Mexico by barrier islands, Padre Island, Mustang Island, St. Joseph's Island, Matagorda Island and Peninsula, and Galveston and Bolivar Peninsulas. There are four passes, Port Isabel, Aransas Pass, Cavallo Pass and Galveston Bay. Tidal rise is only a few inches and does not affect most of the area; run-off is slight except for flash floods.

Three collections made from Aransas and Redfish Bays over 3 months showed great consistency in the species observed at each station during that period, so the study may conveniently be regarded as synoptic. Many of the bays are separated from each other by shallow flats or mud banks, or joined by narrow and shallow bayous and might be expected to show certain peculiarities in their flora.

This paper deals with the diatom flora collected from the surface 5 mm of the sediments by a corer or an Eckman grab, and contains a table showing the stations at which the species occurred. It does not pretend to be an exhaustive taxonomic study of the diatom flora. Sampling was restricted to May through July, and it is probable that the rarer species were not observed.

In order to enlarge the biological record of the Texas Bays and to provide a ready means for identification by students working in the region, photographs and brief descriptions are given.

Editor's note: Because of the importance of the small benthic diatoms in teaching and research along the Gulf Coast, and because of the usefulness of plates in leading students into the genera of the check list, we are including figures which have limitations in resolution.

¹ This paper forms part of A & M Project 273, National Science Foundation.

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The diatoms were identified and photographed from prepared slides in which the sediments were treated with hot HCl for approximately 20 minutes, washed, dried, and mounted in Hyrax.

One or two planktonic species, e.g., *Bacteriastrum varians* and *Skeletonema costatum* were found. *S. costatum* was indeed very common in the sediments of Galveston and Matagorda Bays, where it was assuming bloom proportions when the writer left South Texas. Wood (1959a) records the germination of spores of *S. costatum* from coastal sediments of the Australian continental shelf.

Worthy of comment here is the frequency in the Laguna Madre and Corpus Christi and Aransas Bays of species often associated with fresh water such as *Rhopalodia* spp. and *Epithemia* spp.

The Species Concept in the Diatomaceae

Among the planktonic diatoms, the siliceous skeletons of which are not easily preserved, morphology, including cell shape, appendages, number and distribution of chloroplasts, is used in taxonomy, but even in this case, it is not unusual to find a *Chaetoceros* chain with terminal cells having characters of two recognized species. This implies that even in this group, the classification is not strictly phylogenetic. The sedimentary and epontic diatoms, on the other hand, have long been classified by their siliceous frustules, the cell contents being destroyed to show the detail of the frustule structure. This has been a great advantage, since the frustules are important evidence in the geological record, and it is possible to homologise fossil and living species. The result of this classification has from the taxonomic point of view been unfortunate in that small differences in the detailed structure of frustules have been considered sufficient to erect new species, and type specimens have been carefully preserved in museums in order to perpetuate them. As an example, the variable *Navicula granulata* was considered separate from *N. brasiliensis* though intergrades are as common as typical specimens, and there is no doubt that *N. brasiliensis* is at most an eco-form of *N. granulata*. Further confusion has arisen from the frequent creation of monogeneric and even monospecific families, the absurdity of which is shown by a recent paper by Wood (1959b) who describes and depicts a cell of which one valve has the characteristics of *Coscinodiscus* and the other of *Asteromphalus*—two different families! In Aransas Bay, a diatom cell was found, one valve of which was typical *Coscinodiscus* and the other *Actinocyclus*. From this, it would seem that the classification of discoid diatoms with respect to their frustules has no necessary phylogenetic significance and that the “families” of this group are at most a convention. The present classification of the diatoms is, however, useful, and it is not possible to discard it or substitute a more phylogenetic taxonomy, but it is well that we should bear in mind its limitations, and remember that much of the difficulty of identifying some specimens among the large number of described and figured species is due to the uncritical creation of species by many taxonomists.

Diatom Species

The species will be recorded in alphabetical order.

Genus *ACHNANTHES* Bory, 1822

Frustules usually stipitate, solitary or in short ribbons; valves elliptic or lanceolate,

dissimilar, one with and the other without a raphe, the raphe-less valve having a pseudoraphe; cells in girdle view often chevron-shaped.

1. *Achnanthes biasolettiana* (Kützing) Grunow (Plate 1, Figs. 1, a, b).
Grunow (1880, 22), Hustedt (1933, 379, 823).

Synedra biasolettiana Kützing (1884, 63, 3, 22).

Valves broad linear-elliptic with blunt, produced ends; rapheless valve with very narrow pseudoraphe, without central area; striae transverse; raphe straight, axial area narrow, central area narrow, striae transverse on raphe valve.

Distribution.—Aransas Bay.

2. *Achnanthes brevipes* Agardh (Plate 1, Fig. 2).

Agardh (1824, 1; 1832, 59), Hustedt (1933, 424, 877a-c).

Cells usually in short ribbons or solitary, free or attached by a short stipe; frustules in girdle view chevron-shaped, in valve view linear-elliptic with rounded ends and slightly constricted towards the middle; valve surface punctate in transverse and longitudinal rows and also costate, costae separated by a single row of puncta; raphe with a strong central area dilated centrally forming a stauros.

Distribution.—Laguna Madre, Aransas Bay, San Antonio Bay.

3. *Achnanthes curvirostrum* Brun (Plate 1, Figs. 3 a, b).

Brun (1895, 16, 84, 85), Hustedt (1937, in A.S.A., 415, 21, 22; 1955, 18, 5, 20, 21).

Frustules elliptic-lanceolate with rostrate ends which may be oppositely curved; rapheless valve with straight pseudoraphe, slightly curved at ends, and transverse, punctate striae; raphe curved at ends, striae transverse on raphe valve.

Distribution.—Copano, San Antonio, Matagorda and Galveston Bays.

4. *Achnanthes delicatula* (Kützing) Grunow (Plate 1, Figs. 4 a,b).

Grunow (in Cleve & Grunow, 1880, 22), Hustedt (1933, 389, 836).

Achnanthidium delicatulum Kützing (1844, 75, 3, 21).

Valves elliptic-lanceolate with more or less rostrate ends; rapheless valve with narrow, linear pseudoraphe, raphe valve with straight raphe, narrow axial and small central areas; striae strongly marked, radial, weaker on upper valve.

Distribution.—Baffin Bay, Aransas Bay, Copano Bay.

5. *Achnanthes exilis* Kützing (Plate 1, Figs. 5 a, b).

Kützing (1833, 12), Hustedt (1933, 378, 822).

Valves linear-lanceolate, tapering evenly from the middle to the acutely rounded ends; rapheless valve with narrow linear pseudoraphe, raphe valve with straight raphe, narrow axial area and small, oval central area; striae coarse, parallel, transverse.

Distribution.—Baffin Bay, Aransas Bay, Upper Laguna Madre; Copano, Matagorda, and Galveston Bays; Apalachicola (Florida).

6. *Achnanthes hauckiana* Grunow (Plate 1, Fig. 6).

Grunow (1880, 21), Hustedt (1937, 388, 834).

Valves elliptic to elliptic-lanceolate with blunt to acute, slightly produced ends; rapheless valve with linear to linear-lanceolate pseudoraphe and no central area; raphe valve with straight raphe, narrow axial area, small central area and coarse radial striae.

Distribution.—Aransas (Redfish) Bay.

7. *Achnanthes hungarica* Grunow (Plate 1, Fig. 7).

Grunow (in Cleve & Grunow, 1880, 17, 20), Hustedt (1933, 383, 829).

Valves lanceolate with rounded ends; raphe valve has a narrow axial area and coarse, transverse striae; rapheless valve with a narrow pseudoraphe, coarse striae and a stauros reaching the margin.

Distribution.—Lower Laguna Madre, Copano Bay.

8. *Achnanthes lemmermannii* Hustedt (Plate 1, Fig. 8).

Hustedt (1933, 390, 837), in A.S.A. (1936, 408, 36–39).

Valves elliptic-lanceolate with capitate, blunt ends and almost parallel sides; rapheless valve with narrow pseudoraphe; raphe valve with narrow axial area, equal central area; both valves with coarse, radial striae.

Distribution.—Apalachicola (Florida).

9. *Achnanthes longipes* Agardh (Plate 1, Fig. 9).

Agardh, (1824, 1), Hendey (1951, 42, 1–9, 2, 1–12).

Cells in ribbons or solitary, often stipitate with strong, curved stipe; frustules in valve view linear-elliptic, in girdle view chevron-shaped; valve surface with 2 rows of puncta between strong costae; girdle with finely punctate parallel striae.

Distribution.—Pensacola Bay (Florida).

10. *Achnanthes manifera* Brun (Plate 1, Figs. 10 a,b).

Brun (1895, 16, 86, 87), Hustedt (in A.S.A., 415, 20–22).

Valves elliptic-lanceolate with slightly rostrate ends; raphe valve with straight, narrow pseudoraphe and coarse, punctate striae; lower valve with straight raphe, tapering axial area, stauros becoming diffuse by infusion of striae which are confused in this portion, but fine and parallel in the rest of the valve; a very variable species.

Distribution.—Lower Laguna Madre, Matagorda Bay, St. Andrews Bay (Florida).

11. *Achnanthes tenera* Hustedt (Plate 1, Figs. 11 a,b).

Hustedt (1955, 17, 5, 22–25).

Valves elliptic-lanceolate with acute, subrostrate ends; rapheless valve with narrow pseudoraphe and slightly radiate striae; raphe valve with straight raphe, narrow axial area, small, at times unequal central area and radiate, punctate striae.

Distribution.—Aransas, Baffin, San Antonio, and Matagorda Bays; Pascagoula, (Mississippi). Florida coast.

Genus *ACTINOCYCLUS* Ehrenberg, 1837

Valves circular to elliptical; surface flat at center, sloping to margin; central space usually present, often irregular; pseudo-ocellus at or near margin; surface of valve punctate in radial to fasciculate rows.

12. *Actinocyclus octodenarius* Ehr. (Plate 1, Fig 12 a).

Ehrenberg (1838, 172, 21, 7), Hendey (1937).

A. ehrenbergi Ralfs, 1861 in Hustedt (1927, 525).

Cells solitary, discoid; central space round or irregular with scattered granules; surface flat for about half diameter, then rounded; divided into wedges by hyaline interspaces; markings granular in radial, interrupted fasciculate rows of several orders; hya-

line interspaces may be prominent near border; circular pseudonodule near margin.
Distribution.—Upper Laguna Madre; Copano, San Antonio and Matagorda Bays.

v. *ralfsii* (W. Smith) Hustedt (Plate 1, Fig. 12 b).

Hustedt (1927, 528, 299).

Eupodiscus ralfsii W. Smith, 1856.

Rows of puncta of several orders, the shorter ones alternating and terminating in hyaline areas.

Distribution.—Pensacola Bay (Florida).

v. *sparsa* (Gregory) Hustedt (Plate 1, Fig. 12 b).

Hustedt (1927, 528, 300).

Eupodiscus sparsus Gregory (1857, 710).

Puncta in a fasciculate arrangement, only a few reaching the hyaline central area.

Distribution.—Pascagoula (Mississippi).

v. *tenella* (Brebisson) Hustedt (Plate 1, Fig. 12 c).

Hustedt (1927, 530, 300), *Eupodiscus tenellus* Brebisson (1854, 257, 1, 9).

Valves flat, thin walled; puncta sparse, radial.

Distribution.—Laguna Madre.

Genus *ACTINOPTYCHUS* Ehr., 1839 em. van Heurck, 1890

Frustules discoid; with undulate valve surface; valves with six or more alternately raised and depressed sectors, areolate on outer, punctate on inner surface; central area usually hyaline, circular to polygonal.

13. *Actinoptychus campanulifer* A. Schmidt (Plate 1, Fig. 13).

A.S.A. (1875, 29, 13–15).

Valves small, discoid with 6 sectors; surface coarsely areolate, areolae larger proportionally than those of *A. senarius* (*A. undulatus*); inner layer coarsely punctate; central area about $\frac{1}{3}$ valve diameter.

Distribution.—Upper Laguna Madre, Aransas Bay, Matagorda Bay, Copano Bay, Galveston Bay.

14. *Actinoptychus senarius* (Ehr.) Ehr.

Ehrenberg (1843, 6, 1, 1, 27), Hendey (1951, 32).

Actinocyclus senarius Ehr. (Plate 1, Fig. 14).

Ehr. (1838, 172, 21, 6).

Actinoptychus undulatus Kützinger (1844, 132, 1, 24).

Frustules discoid; valve with 6 sectors; surface coarsely areolate, with larger areolae towards margin and inner layer of puncta radiating; each sector with a short spine under margin.

Distribution.—Upper Laguna Madre, Aransas Bay, Matagorda Bay, Galveston Bay.

15. *Actinoptychus taeniatus* Hustedt (Plate 1, Fig. 15).

Hustedt (1955, 7, 52, 1, 2).

Valves circular, undulate with 6 sectors and large, hyaline central space; surface coarsely and irregularly areolate; inner layer punctate with puncta in straight or slightly diverging rows and 2 systems of oblique rows; deeper sectors with coarser puncta; processes at middle of upper sectors on valve margins.

Distribution.—Upper Laguna Madre, Aransas Bay, Matagorda Bay, Galveston Bay.

Genus AMPHIPRORA Ehrenberg, 1843

Frustule twisted on the longitudinal axis, constricted in the middle; girdle complex, striate; valves lanceolate; raphe confined within a sigmoid keel or valve extension; striate transverse, punctate.

16. *Amphiprora alata* (Ehr.) Kützing (Plate 1, Figs. 16 a,b).

Kützing, (1844, 107, 3, 63).

Navicula alata Ehrenberg (1840, 212).

Cells solitary or in short ribbons; frustules in valve view linear with acute apices, in girdle view constricted and twisted in the middle; axial area raised to form a sigmoid keel bearing the raphe; valve striate, keel coarsely punctate; girdle bands multiple, striate.

Distribution.—Upper Laguna Madre, Aransas Bay.

17. *Amphiprora gigantea* Grunow (Plate 1, Fig. 17).

Grunow (1860, 568). Cleve (1894, 18, 1, 6).

Frustule strongly constricted, and twisted; keel with hyaline margin, broader towards ends, junction line uniformly arcuate; keel puncta in oblique rows, striae curved, divergent from central nodule; raphe strongly sigmoid; girdle with numerous bands.

Distribution.—Upper Laguna Madre, Aransas Bay, Matagorda Bay, San Antonio Bay, numerous.

Genus AMPHORA Ehrenberg, 1840

Valves asymmetrical along longitudinal axis and cuneate in transverse section; raphe excentric, often curved.

18. *Amphora acuta* Gregory

Gregory (1957, 21, 524).

Valves lunate with acute ends; ventral margin straight, ventral side very narrow; central nodule dilated to a stauros; striae transverse, punctate.

v. *arcuata* (A.S.) Cleve (Plate 2, Fig. 18).

Cleve (1895, 128).

A. arcuata A.S.A. (1875, 26, 26–29).

Dorsal margin strongly arcuate with rostrate ends, ventral margin slightly to strongly biarcuate; raphe marginal on ventral margin, transverse, punctate coarse striae.

Distribution.—Aransas Bay, Upper Laguna Madre, St. Andrews Bay (Florida).

19. *Amphora angularis* Gregory (Plate 2, Fig. 19).

Gregory (1855, 39, 3, 6), A.S.A. (1875, 25, 83).

Frustules in girdle view elliptic-lanceolate with constricted middle and bluntly produced ends; valves with arcuate dorsal and straight ventral margins, raphe closer to latter; striae transverse, punctate, somewhat coarse.

Distribution.—Upper Laguna Madre, San Antonio Bay.

20. *Amphora angusta* Gregory (Plate 2, Fig. 20).

Gregory (1857, 510, 12, 66). Cleve (1895, 135).

Cells solitary; frustules in girdle view linear-elliptic, in valve view arcuate with

straight ventral margin; raphe straight, near ventral margin; striae transverse, marginal striae more distinct.

Distribution.—Laguna Madre, Corpus Christi and Aransas Bays; St. Andrews Bay (Florida).

21. *Amphora arenaria* Donkin (Plate 2, Fig. 21).

Donkin (1858, 31, 3, 16), A.S.A. (1875, 40, 8–10), Boyer (1927, 269).

Frustules rectangular with rounded ends; girdle without longitudinal lines, hyaline; valves linear, ends rounded, ventral margin sinuate or biarcuate; raphe biarcuate with recurved apices; striae very fine, more marked on dorsal margin.

Distribution.—Upper Laguna Madre, Aransas Bay (rare).

22. *Amphora aspera* Petit ? (Plate 2, Fig. 22).

Petit (1877, 19, 4, 9), Cleve (1895, 128, 3, 22).

Valves semi-lanceolate, dorsal margin arcuate, slightly undulate; beaked ends; ventral margin undulate, slightly gibbous centrally; striae on dorsal side punctate, forming undulate longitudinal lines.

Distribution.—Upper Laguna Madre.

23. *Amphora capensis* A.S. (Plate 2, Fig. 23).

A.S.A. (25, 49, 50), Cleve (1895, 115).

Frustules elliptical with broad, rostrate ends; valves arcuate dorsal margin convex with slightly rostrate ends, ventral margin concave near ends; raphe sinuate; stauros present; surface with coarse, transverse striae.

Distribution.—St. Louis Bay, Biloxi (Mississippi).

24. *Amphora coffaeiformis* (Agardh) Kützing (Plate 2, Fig. 24 a, b).

Kützing (1844, 108), A.S.A. (1875, 26, 56–58), Boyer (1927, 260).

Frustules elliptic-lanceolate with produced ends, truncate; girdle with several longitudinal divisions; valves strongly arcuate on dorsal, straight or concave on ventral margins, rostrate or capitate; raphe near ventral margin; striae fine on dorsal side.

Distribution.—On *Diplanthera* in Laguna Madre, Corpus Christi Bay, Aransas Bay (at times dominant), Matagorda Bay (rare); Baffin Bay, Copano Bay.

25. *Amphora decussata* Grunow (Plate 2, Fig. 25).

Grunow (1867, 23), Cleve (1895, 128, 4, 1).

Frustules elliptical, truncate; girdle with numerous divisions; striate; valves with arcuate dorsal, and straight or almost straight ventral margins, ends acute; raphe close to ventral margin; stauros narrow; puncta forming slightly undulating longitudinal and transverse rows.

Distribution.—Lower Laguna Madre.

26. *Amphora delphinea* Bailey (Plate 2, Fig. 26).

Bailey (1861, 1, 1), A.S.A. (1875, 40, 25–27), Cleve (1895, 134), Boyer (1927, 270).

Frustule rectangular-elliptic, may be gibbous in the middle; valves linear to lunate with obliquely rounded ends, central nodule forming a stauros; raphe sinuate, striae transverse, fine.

Distribution.—St. Louis Bay (previous record from Pensacola).

27. *Amphora dubia* Gregory (Plate 2, Fig. 27 a, b).

Gregory (1857, 514, 13, 76), Cleve (1895, 102, 4, 5, 6).

Frustules in girdle view sub-elliptic; valves with arcuate dorsal and straight to convex ventral margins; raphe straight or slightly curved; striae transverse, punctate.

Distribution.—Upper Laguna Madre, Corpus Christi Bay, Aransas Bay, Matagorda Bay, Galveston Bay.

28. *Amphora egregia* A.S. (Plate 2, Fig. 28 a, b).

A.S.A. (1875, 28, 13–15), Boyer (1927, 257).

Frustules in girdle view elliptic with truncate ends; valves lunate with rounded, retrorse ends, ventral margin biarcuate, gibbous centrally, raphe biarcuate; surface with a series of coarse transverse striae; ventral side with a row of strong radial striae; girdle with 2–4 rows of rounded puncta.

Distribution.—Aransas Bay, Laguna Madre.

29. *Amphora graeffii* (Grunow) Cleve (Plate 2, Fig. 29).

Cleve (1895, 113).

A. graeffii var. Grunow (in A.S.A., 25, 40).

Valves with arcuate dorsal and straight to slightly concave ventral sides, ends slightly rostrate; raphe straight to slightly biarcuate; striae almost parallel to transverse axis with a ridge between dorsal and ventral margins. Cleve (l.c.) considers that this species is close to if not identical with *A. grevilleana* Gregory, 1857.

Distribution.—Laguna Madre, Aransas Bay.

30. *Amphora granulata* Gregory (Plate 2, Fig. 30 a, b).

Gregory (1857, 21, 525), Cleve (1895, 123).

Frustules in girdle view linear-elliptic, in valve view with arcuate dorsal and straight ventral margins and capitate ends; raphe straight, close to ventral margin; striae coarse, transverse.

Distribution.—Upper Laguna Madre, Baffin, Corpus Christi, Aransas and San Antonio Bays.

31. *Amphora hyalina* Kützing (Plate 2, Fig. 31).

Kützing (1844, 108, 30, 18), Cleve (1895, 126, 127), Boyer (1927, 264).

Frustules in girdle view sub-rectangular with rounded corners; valves with convex dorsal and straight ventral margins and acute ends; raphe straight, striae fine.

Distribution.—Upper Laguna Madre, Aransas and Copano Bays; Florida.

32. *Amphora javanica* A.S. (Plate 2, Fig. 32 a, b).

A.S.A. (1875, 27, 27, 30–33), Cleve (1895, 104).

Frustules in girdle view rectangular with evenly rounded ends; valves with arcuate dorsal and straight ventral margins; raphe biarcuate, almost median; striae coarse, interrupted to form irregular, wavy lines, equally evident on dorsal and ventral sides of the raphe.

Distribution.—Upper Laguna Madre, Aransas Bay.

33. *Amphora laevis* Gregory (Plate 2, Fig. 33 a, b).

Gregory (1857, 514, 74), Boyer (1927, 268).

Frustules membranaceous, rectangular in girdle view, with slightly constricted middle

and rounded, sub-truncate ends; girdle zone with numerous intercalary bands; valves with arcuate, slightly notched and slightly sinuate ventral margins and a marked stauros; striae evident, transverse.

Distribution.—Upper Laguna Madre, Aransas Bay.

34. *Amphora mexicana* A.S. (Plate 2, Fig. 34).

A.S.A. (1875, 27, 47, 48), Cleve (1895, 105).

Frustules elliptic, truncate in girdle view; in valve view lunate with slightly concave ventral margin; raphe biarcuate, axial area not distinct; longitudinal line near margin on dorsal side.

Distribution.—Upper Laguna Madre; Baffin, Aransas and Espiritu Santo Bays.

35. *Amphora obtusa* Gregory (Plate 2, Fig. 35 a, b).

Gregory (1857, 12, 60), A.S.A. (1875, 40, 4–7, 11–13), Cleve (1895, 131).

Frustules rectangular in girdle view, with rounded ends and may be slightly constricted in the middle; girdle with a few intercalary bands; valves linear with rounded ends, arcuate dorsal and straight ventral margins; raphe biarcuate, striae faint, transverse.

Distribution.—Upper Laguna Madre, Aransas Bay.

36. *Amphora proteus* Gregory (Plate 2, Fig. 36 a-c).

Gregory (1857, 518, 81), A.S.A. (27, 3), Cleve (1895, 103).

Frustules variable, in girdle view elliptic to oblong with rounded ends, narrow to broad; valves lunate, acute, sometimes arcuate with straight ventral margin; raphe biarcuate; central area variable; striae transverse punctate.

Distribution.—Lower and Upper Laguna Madre, Aransas, Corpus Christi, Matagorda and Galveston Bays; Pensacola and St. Andrews Bay (Florida).

37. *Amphora robusta* (Gregory) (Plate 3, Fig. 37).

Gregory (1857, 516, 13, 79), Cleve (1895, 103).

Frustules elliptic; valves with strongly arcuate dorsal, and slightly sinuate or straight ventral margins; raphe nearly central with marked central area and tapering axial area; surface with radial costae.

Distribution.—Baffin Bay, Lower Laguna Madre.

38. *Amphora spectabilis* (Gregory) (Plate 3, Fig. 38).

Gregory (1857, 516, 30 a-c), Cleve (1895, 132).

Frustules in girdle view oblong with rounded ends; girdle zone with numerous striate divisions; valves arcuate, ends rounded on dorsal, slightly capitate on ventral margin; raphe biarcuate; striae frequently branched, finer on ventral side of raphe.

Distribution.—Corpus Christi Bay (dominant on occasion).

39. *Amphora turgida* Gregory (Plate 3, Fig. 39).

Gregory (1857, 510, 63), Wood (1961, 690, 54, 147).

Frustule nearly orbicular with short, square, produced apices; valves nearly semi-circular to elliptical with straight or concave ventral margins and capitate apices; nodules conspicuous, raphe close to ventral margin; striae radiate.

Distribution.—Laguna Madre, Baffin Bay, Aransas Bay, Matagorda Bay, Florida coast.

40. *Amphora terroris* Ehrenberg (Plate 3, Fig. 40 a, b).

Ehrenberg (1853, 526), A.S.A. (1875, 25, 17–19, 32–34), Boyer (1927, 262).

A. cymbifera Gregory (1857, 526).

Frustules elliptical, ends produced, truncate; girdle with intercalary bands; valves with arcuate dorsal, concave ventral margins, capitate; raphe close to ventral margin; striae indistinctly punctate.

Distribution.—Aransas Bay, Redfish Bay.

41. *Amphora weissflogii* A.S. (Plate 3, Fig. 41 a, b).

A.S.A. (1875, 25, 58), Cleve (1895, 116), Boyer (1927, 259).

Frustules rectangular indented in the middle, border narrow, hyaline girdle with four intercalary bands; valves with arcuate dorsal margin, slightly indented in the middle, ventral margin slightly gibbous; ends of valves rostrate to capitate, slightly retrorse; central nodule forming stauros; raphe close to ventral margin; striae transverse.

Distribution.—Aransas Bay, Matagorda Bay; St. Andrews Bay (Florida).

42. *Amphora* sp. 1. (Plate 3, Fig. 42).

Valve with arcuate dorsal margin, ventral margin slightly constricted near apices; raphe slightly arcuate, median; striae faint, transverse.

Distribution.—Matagorda Bay.

43. *Amphora* sp. 2. (Plate 3, Fig. 43).

Valves with arcuate dorsal and straight ventral margins, ends slightly rostrate, raphe slightly biarcuate; stauros present; striae somewhat coarse, radial, clearly punctate.

Distribution.—Aransas Bay.

Genus *ASTEROMPHALUS*

Cells discoid, valves circular to oval with raised, hyaline rays separating punctate sectors, one ray being double; central area hyaline.

44. *Asteromphalus flabellatus* (Brebisson) Greville (Plate 3, Fig. 44).

Greville (1869, 160), Boyer (1927, 74).

Spatangidium flabellatum Breb. (1857, 297).

Valves oval; hyaline area about half valve diameter; segments areolate, connected by straight rays; hyaline rays about 6, strong.

Distribution.—Corpus Christi Bay, Aransas Bay.

Genus *AULISCUS* Ehr., 1843

Frustules cylindrical; girdle finely punctate; valves circular to elliptic, central area hyaline; two or three sub-marginal processes, which are short, cylindrical; surface of valve granulate or linear.

45. *Auliscus reticulatus* Greville (Plate 3, Fig. 45).

Greville (1863, 46, 2, 10), Hustedt (1929, 513, 288).

Frustules discoid with broadly elliptic, almost circular valves; rounded central area, ribs roughly concentric from central area to the 2 processes, and radial in between, united by reticulate cross ribs, and radial between the raised areas of the valves.

Distribution.—Upper Laguna Madre, Aransas Bay, Matagorda Bay.

Genus *BACILLARIA*

Valves linear with tapering ends; raphe on punctate keel as in *Nitzschia*; the genus is characterized by a peculiar lateral motion of the cells with respect to each other, the colony varying from palisade to arrow-head, to z-shaped.

46. *Bacillaria paxillifer* (O. F. Müller) Nitzsch (Plate 3, Fig. 46).

Nitzsch (1817, 75), Crosby & Wood (1959, 40, 8, 119).

Vibrio paxillifer O.F.M. (1786, 54).

Also known as *Nitzschia paradoxa*, *Bacillaria paradoxa*.

Cells colonial, arranged in palisade formation, able to slide laterally with respect to each other with a characteristic motion; frustules linear with tapering ends; keel puncta strong, striae transverse.

Distribution.—Pascagoula (Mississippi).

Genus *BACTERIASTRUM*

Cells in straight chains; joined by marginal extensions broken by several apertures and with several to numerous setae at right angles to the chain axis.

47. *Bacteriastrum varians* Lauder (Plate 3, Fig. 47).

Lauder (1864, 8, 3, 1–6), Allen & Cupp (1935, 133, 48).

Cells in straight chains; frustules nearly equal in width and length; setae 10–26, at right angles to chain axis; apertures small; terminal setae with fine spines in spiral rows.

Distribution.—Pensacola (Florida), common in the sediments.

Genus *BIDDULPHIA* Gray, 1831

Cells in chains or solitary; when in chains, united by processes; frustules usually more or less rectangular in girdle view, elliptical or elliptic-crenate in valve view; processes at each angle and two spines also frequently present; surface usually reticulate, or punctate.

48. *Biddulphia aurita* (Lyngbye) Brebisson (Plate 3, Fig. 48).

Brebisson (1838, 12).

Cells solitary, in straight or zig-zag chains, frustules in valve view lanceolate; processes inflated at base, tapering to ends; valves with small radial puncta and small lateral spines in convex central area; girdle sharply differentiated from valve; plastids numerous, reinform to elliptic.

Distribution.—Aransas and Matagorda Bays.

49. *Biddulphia levis* Ehrenberg (Plate 3, Fig. 49).

Ehrenberg (1843, 122), Hustedt (1929, 852, 506).

Frustules solitary or in short chains; cylindrical, longer than broad; valves flat or convex with deep mantle; processes much reduced, often only as hyaline eyes at valve corners; valves finely areolate in diagonal rows; small spinelets on valve surface.

Distribution.—Matagorda Bay; Fort Pike (Mississippi).

50. *Biddulphia longicuris* Greville (Plate 3, Fig. 50).

Greville (1859, 163, 8, 10), Cupp (1943, 154, 111).

Cells in girdle view cylindrical with rounded valves having two long, tapering proc-

esses oblique to the valves and two long-curved spines much closer to center of valve, valve constricted above girdle; girdle and valves reticulate.

Distribution.—Aransas Bay.

51. *Biddulphia mobiliensis* (Bailey) Grunow (Plate 3, Fig. 51).

Grunow (in van Heurck 1880–85, 103a), Boyer (1901, 698; 1927, 122).

Zygoceros (Denticella) mobiliensis Bailey (1851, 40).

Cells solitary or united by spines; valves elliptic-lanceolate; surface convex with flat center, separated from rest of valve by a slightly elevated ridge which extends in two more or less sigmoid lines from one process to the other; on opposite sides of the central portion is a small, conical projection from which extend one or two long, slender spines; processes slender, capitate; valve surface delicately punctate.

Distribution.—Upper Laguna Madre, Aransas Bay, Matagorda Bay.

52. *Biddulphia pulchella* Gray (Plate 3, Fig. 52).

Gray (1821, 1, 294), Hendey (1951, 34).

Cells solitary or in short chains; frustules cylindrical in girdle view, elliptical in valve view; valves with undulating sides divided by costae into 3 or more sections; ends with large, globular or subconical processes, finely porulate; valve surface between costae coarsely areolate, areolae concentric in center, concentrically with processes towards margin; in girdle view aerolae with a longitudinal and transverse arrangement; girdle punctate, striate; plastids numerous.

Distribution.—Aransas Bay.

53. *Biddulphia subaequa* (Kützing) Ralfs (Plate 3, Fig. 53).

Ralfs (in Pritch 1861, 848), Hustedt (1927, 849, 503).

Odontella subaequa Kützing (1844, 137, 18, 8, 4–5).

Frustules longer than broad; valves dome-shaped, with short, blunt, slightly flaring processes; valve surface with short spinelets and fine, more or less radial areolae.

Distribution.—Upper Laguna Madre, Matagorda Bay, Pascagoula (Mississippi).

54. *Biddulphia* sp. (Plate 3, Fig. 54).

Frustules with rectangular girdle and tapering valves, the latter with upper portion oblique to transverse axis; upper part of valve with coarse, transverse areolae, mantle with finer oblique areolae; small blunt processes and long spines at valve ends.

Distribution.—Matagorda Bay.

Genus *CALONEIS* Cleve, 1894

Valves convex, linear to linear lanceolate with transverse, smooth or punctate striae crossed by one or more longitudinal lines parallel to margins.

55. *Caloneis formosa* (Gregory) Cleve (Plate 3, Fig. 55).

Cleve (1894, 57).

Navicula formosa Gregory (1856, 42, 6).

Valves narrow lanceolate with obtuse ends; axial and central areas forming an irregularly lanceolate space, usually dilated unilaterally in the middle; striae almost parallel, radiate at ends; longitudinal lines median.

Distribution.—Aransas Bay; Pascagoula (Mississippi).

56. *Caloneis latiuscula* (Kützing) Cleve (Plate 3, Fig. 56).

Cleve (1894, 61), A.S.A. (1911, 271, 1, 2), Cleve-Euler (1953, 1134b).

Navicula latiuscula Kützing (1844, 93, 5, 40).

Valves elliptic to lanceolate, axial and central areas forming an irregularly lanceolate space; striae parallel, finely punctate, of varying length; longitudinal lines marginal.

Distribution.—Aransas Bay; Pensacola (Florida).

57. *Caloneis liber* (W. Smith) Cleve (Plate 4, Fig. 57).

Cleve (1894, 26, 54), A.S.A. (1881, 50, 16–18), Boyer (1927, 310).

Navicula liber W. Smith (1863, 48).

Valves oblong, elliptic with rounded ends; axial area very narrow; central area small, circular; striae parallel, transverse, radial at ends of valve; longitudinal lines median, may be single or double.

Distribution.—Lower Laguna Madre, Aransas Bay.

58. *Caloneis permagna* (Bailey) Cleve (Plate 4, Fig. 58).

Cleve (1894, 59), A.S.A. (1911, 271, 30, 31), Boyer (1916, 82, 21, 1; 1927, 313), Cleve-Euler (1953, 1120).

Pinnularia permagna Bailey (1850, 40, 2, 28, 38).

Valves rhombic-lanceolate, margins sometimes slightly triundulate; axial and central areas forming an irregularly lanceolate space; longitudinal lines broad or double, median, striae radial.

Distribution.—Corpus Christi Bay.

59. *Caloneis probabilis* (A.S.) Cleve (Plate 4, Fig. 59).

Cleve (1894, 56).

Navicula probabilis A.S.A., (50, 46–48).

Valves linear-elliptic with rounded but slightly produced ends; raphe sinuate; axial area narrow, central area small; striae coarse, punctate, perpendicular to raphe, longitudinal lines double.

Distribution.—Aransas Bay.

Genus *CAMPYLODISCUS* Ehrenberg, 1841

Valves orbicular to cordate, saddle-shaped, the frustule consisting of two saddle-shaped valves at right angles to each other, girdle varying in shape according to position; raphe marginal; valve surface with radial costae and a hyaline central space or a central line.

60. *Campylodiscus biangulatus* Greville (Plate 4, Fig. 60).

Greville (1863, 4, 2), A.S.A. (1875, 14, 18–22).

Valves heart-shaped or sub-circular, strongly convolute; costae strong, bifurcate near margin, reaching linear-ovate median space; costae very strong in valve view.

Distribution.—Laguna Madre.

61. *Campylodiscus echeneis* Ehr. (Plate 4, Fig. 61).

Ehrenberg (1841, 206), A.S.A. (1886, 54, 36), Boyer (1916, 130, 37, 5; 1927, 552).

Valves circular; costae indistinct, short, marginal; surface with rows of round or

elongate puncta, unequal and at irregular intervals, converging towards a lanceolate median space.

Distribution.—Pensacola Bay, Florida.

62. *Campylodiscus hibernicus* Ehr. (Plate 4, Fig. 62).

Ehrenberg (1845, 54), A.S.A. (1876 55, 9–14), Boyer (1916, 130, 37, 5; 1927, 555).

Valves subcircular, with cruciform median space; highly convolute; in semi-girdle view cordate with radial ribs extending to median space.

Distribution.—Upper and Lower Laguna Madre.

Genus *CAMPYLOSIRA* Grunow, 1882

Frustules in ribbons, united by middles of valves; valves with unequally gibbous margins; punctate.

63. *Campylosira cymbelliformis* (A.S.) Grunow (Plate 4, Fig. 63).

Grunow (in van Heurck 1880–85, 45, 43), Hustedt (1929, 128, 650).

Frustules in ribbons, united by the middles of the valves; in girdle view with undulate margins, gibbous in the middle, and swollen at the ends; valves rostrate with unequally gibbous margins the dorsal being more convex; valves strongly punctate.

Distribution.—Lower Laguna Madre, Corpus Christi, Aransas, Copano Bays.

Genus *COCONEIS* Ehrenberg, 1935

Valves elliptical dissimilar, epontic; one valve with raphe, the other differently marked and with a pseudoraphe, frustule usually with a rim or annulus.

64. *Cocconeis apiculata* A.S. (Plate 4, Fig. 64).

A.S.A. (1894, 198, 30), Boyer (1927, 251).

Frustules elliptic with apiculate ends; rapheless valve with punctate striae parallel, transverse; pseudoraphe narrow.

Distribution.—Aransas Bay.

65. *Cocconeis costata* Gregory (Plate 4, Fig. 65).

Gregory (1855, 39, 4, 10), Hustedt (1923, 332, 785).

Valves elliptic; rapheless valve with double rows of puncta between the radial striae; pseudoraphe narrow; raphe valve with tapering striae, a narrow rim; straight raphe and narrow areas, often with a narrow stauros.

Distribution.—Lower Laguna Madre.

66. *Cocconeis disculoides* Hustedt (Plate 4, Fig. 66 a, b).

Hustedt (1955, 17, 5, 8–11; 7, 8).

Valves elliptic; rapheless valve with a narrow, lanceolate pseudoraphe semiradiate striae, which are coarse, interrupted, forming several longitudinal lines; raphe valve with straight raphe and narrow axial area; striae punctate, only identifiable as such in the marginal zone, otherwise consisting of fine puncta.

Distribution.—Aransas Bay.

67. *Cocconeis disculus* (Schumann) Cleve (Plate 4, Fig. 67).

Cleve (1895, 172), Hustedt (1933, 345, 799).

Navicula disculus Schumann (1864, 21, 2, 23).

Valves elliptic to elliptic-lanceolate; rapheless valve with coarse, interrupted striae giving the effect of a series of dashes; pseudoraphe lanceolate; raphe valve finely striate, striae radial, raphe straight with very narrow areas.

Distribution.—Upper and Lower Laguna Madre, Baffin Bay, Aransas and Matagorda Bays.

68. *Cocconeis distans* Gregory (Plate 4, Fig. 68).

Gregory (1857, 18, 1, 23), Hustedt (1933, 343, 797).

Valves elliptic; rapheless valve with finely punctate margin and distant radial ribs with several irregular puncta therein; pseudoraphe linear; raphe valve with regularly punctate, radial striae; raphe straight; areas small.

Distribution.—Upper and Lower Laguna Madre, Aransas, Copano and Matagorda Bays.

69. *Cocconeis heteroidea* Hantzsch (Plate 4, Fig. 69).

Hantzsch (1863, 1, 21), Boyer (1927, 248), Hustedt (1933, 356, 811).

Cells solitary, usually attached; valves circular to elliptic; rapheless valve with fine radial striae interrupted by hyaline areas and crossed by curved longitudinal lines; raphe valve with strongly marked radial striae; central nodule indistinct; raphe sigmoid, margin hyaline.

Distribution.—Lower Laguna Madre.

70. *Cocconeis maxima* (Grunow) Perag. (Plate 4, Fig. 70).

Peragallo (1897, 18, 3, 1-4), Hustedt (1933, 335, 789).

Mastogloia maxima Grunow (1863, 516, 4, 1).

Cocconeis lorenziana A.S.A. (1894, 191, 28-34).

Valves elliptic; rapheless valve with short marginal ribs, which submarginally are separated by a double row of puncta and more centrally consist of rows of puncta; pseudoraphe lanceolate; raphe valve with straight raphe, narrow areas, fine, punctate, radial striae not reaching margin, which is hyaline, with an inner ring of fine striae separated by puncta.

Distribution.—Lower Laguna Madre.

71. *Cocconeis pensacolae* A.S. (Plate 4, Fig. 71 a, b).

A.S.A. (1894, 192, 4 a-f).

Valves elliptic; central area of rapheless valve elliptic, wide; striae marginal, punctate, radiate; raphe valve with straight raphe, fine, marginal striae and wide, elliptic central area.

Distribution.—Lower Laguna Madre, Aransas and San Antonio Bays; Pensacola, St. Andrews Bay (Florida).

72. *Cocconeis placentula* Ehr. (Plate 4, Fig. 72).

Ehrenberg (1838, 194), Boyer (1916, 57, 16, 29; 1927, 244), Hustedt (1933, 347, 802).

Valves elliptical; rapheless valve clearly punctate in radial striae forming zig-zag

longitudinal lines; pseudoraphe narrow, linear; raphe valve with narrow raphe and axial area, striae fine, radial, punctate; loculi rudimentary.

Distribution.—Laguna Madre; Baffin Bay, Aransas Bay, Matagorda Bay, St. Andrews Bay (Florida).

73. *Cocconeis scutellum* Ehr. (Plate 4, Fig. 73 a).

Ehrenberg (1838, 194), Hustedt (1931, 337, 790).

Cells epiphytic, attached, solitary; frustule in valve view broadly elliptic; rapheless valve with coarse radial puncta and marked pseudoraphe, finely punctate at margin with puncta in rows; raphe valve with straight raphe, small central area, finely radially striate with broad marginal annulus.

Distribution.—Laguna Madre, Baffin, Corpus Christi, Aransas and Matagorda Bays; St. Andrews Bay (Florida).

v. stauroneiformis W. Smith (Plate 4, Fig. 73 b).

W. Smith (1853, 30, 34).

Central area of raphe valve forming a stauros reaching the margin.

Distribution.—Lower Laguna Madre, Corpus Christi and Aransas Bays.

74. *Cocconeis* sp. (Plate 4, Fig. 74).

Valves elliptical; pseudoraphe sigmoid excentric, narrow; striae coarse, punctate, radial. Raphe valve unknown.

Distribution.—Laguna Madre.

Genus *COSCINODISCUS* Ehrenberg, 1838

Frustules cylindrical, usually solitary; valves circular or elliptic, rarely reniform; surface areolate or punctate; central area present or absent; central rosette of larger cells may occur.

75. *Coscinodiscus argus* Ehr. (Plate 5, Fig. 75).

Ehrenberg (1829, 39), Kolbe (1954, 28).

Frustules discoid; valves with a small, angular central space; areolate; areolae larger near center, decreasing, increasing and decreasing again to margin.

Distribution.—Upper Laguna Madre, Corpus Christi, Aransas, and Matagorda Bays.

76. *Coscinodiscus asteromphalus* Ehr. (Plate 5, Fig. 76).

Ehrenberg (1844, 77), Boyer (1916, 23, 2, 16; 1927, 56).

Valves convex with a small central space surrounded by a rosette of large, polygonal cells from which radiate hexagonal areolae increasing to about halfway to margin, then decreasing.

Distribution.—Aransas, Matagorda and Galveston Bays; Lake Pontchartrain (Louisiana).

77. *Coscinodiscus blandus* A.S. (Plate 5, Fig. 77).

A.S.A. (1886, 59, 35).

Valves almost flat; areolae coarse, irregularly arranged, no central area or rosette.

Distribution.—Pensacola Bay (Florida), Type loc. Gulf of Mexico (A.S.).

78. *Coscinodiscus concavus* Gregory (Plate 5, Fig. 78).

Gregory (1857, 31, 500), Boyer (1927, 45).

Cells solitary; valves nearly flat; central space absent; areolae of constant size, irregular in center but somewhat concentric near margin.

Distribution.—Laguna Madre, Baffin, Aransas, San Antonio, Matagorda and Galveston Bays.

79. *Coscinodiscus decrescens* Grunow (Plate 5, Fig. 79).

Grunow (in A.S.A. 1878, 61, 7–10), Hustedt (1927, 430, 233).

Cells with convex valves, strongly areolate, areolae much larger in the center than at the periphery; without the deep margin of *C. marginatus*.

Distribution.—Matagorda and Galveston Bays; Pascagoula (Mississippi).

80. *Coscinodiscus divisus* Grunow (Plate 5, Fig. 80).

Grunow (1878, 125), Rattray (1889, 499), Hustedt (1928, 409, 218).

Valves with irregularly radiating fascicules of areolae arranged in irregular orders, with an irregular central rosette.

Distribution.—Matagorda and Galveston Bays.

81. *Coscinodiscus elegans* Greville (Plate 5, Fig. 81).

Greville (1866, 3, 1, 6), A.S.A. (58, 7; 163, 10), Boyer (1927, 59).

Valves with rows of coarse puncta radiating from the margin to the center and a depressed central area about $\frac{1}{3}$ diameter of valve, containing scattered to radial puncta.

Distribution.—Corpus Christi Bay.

82. *Coscinodiscus excentricus* Ehr. (Plate 5, Fig. 82).

Ehrenberg (1840, 146), Hustedt (1927, 388, 201).

Cells discoid; valves flat with narrow margins, having spinules in an irregular circle; areolae in slightly curved, nearly parallel rows, but with a varying arrangement which may differ on each valve; no obvious central area or rosette.

Distribution.—Upper Laguna Madre, Corpus Christi, Aransas, Copano, Matagorda and Galveston Bays.

83. *Coscinodiscus kuetzingii* A.S. (Plate 5, Fig. 83).

A.S.A. (1878, 57, 17, 18), Hustedt (1927, 398, 209).

Frustules drum-shaped, flat; valves areolate, areolae decreasing slightly from center to margin, arranged in fasciculae giving a V formation and a secondary arrangement consisting of a series of intersecting curves.

Distribution.—Aransas Bay.

84. *Coscinodiscus lineatus* Ehr. (Plate 5, Fig. 84).

Ehrenberg (1838, 129, 37), Hustedt (1928, 393, 204).

Frustules discoid; valves flat with hexagonal areolae arranged in rows in 3 directions at 120° angles; no rosette or central area; irregular forms intergrade with a number of other species.

Distribution.—Upper and Lower Laguna Madre, Aransas, Copano, San Antonio, Matagorda and Galveston Bays; Apalachicola (Florida).

85. *Coscinodiscus moelleri* A.S. (Plate 5, Fig. 85).
A.S.A. (1878, 59, 17), Hustedt (1928, 395, 206).

Valves convex, areolate; areolae diminishing from center to margin in an arcuate-tangential arrangement; small papilla in center.

Distribution.—Aransas, Copano, and Matagorda Bays.

86. *Coscinodiscus marginatus* Ehr. (Plate 5, Fig. 86).
Ehrenberg (1841, 142), Hustedt (1927, 416, 223).

Valves flat, convex at margin; surface strongly areolate, areolae hexagonal, diminishing to margin, internal pores usually obvious; no rosette or central area; margin with strongly marked, radiate structure.

Distribution.—Aransas, San Antonio, Matagorda and Galveston Bays.

87. *Coscinodiscus nodulifer* A.S. (Plate 5, Fig. 87).
A.S.A. (1878, 59, 20–23), Hustedt (1928, 426, 229).

Frustules discoid; valves flat; surface coarsely areolate, usually without specific arrangement, but occasionally radial; a small central area present with a small papilla or nodule.

Distribution.—Laguna Madre, Baffin, Aransas, Copano and Galveston Bays.

88. *Coscinodiscus oculus iridis* Ehr. (Plate 5, Fig. 88).
Ehrenberg (1841, 147), Hustedt (1927, 454, 252).

Cells discoid; valves slightly concave; hyaline area may be present; rosette usually large, areolae large, refractile, somewhat radial and in two intersecting excentric curved rows; marginal cells small.

Distribution.—Matagorda Bay.

89. *Coscinodiscus radiatus* Ehr. (Plate 5, Fig. 89).
Ehrenberg (1840, 148, 3, 1), Hendey (1937, 250).

Frustules discoid; valves flat with polygonal areolae decreasing in size to margin; no rosette or central area.

Distribution.—Upper Laguna Madre, Corpus Christi, Aransas, San Antonio, Matagorda and Galveston Bays; Pascagoula (Mississippi).

90. *Coscinodiscus rothii* (Ehr.) Grunow (Plate 5, Fig. 90).
Grunow (1878, 125), Hustedt (1928, 400, 211).
Heterostephania rothii Ehrenberg (1854, 35a, 14b, 4, 5).

Frustules convex with depressed center; valves with fasciculate areolae forming secondary rows at an angle of about 120°; small center rosette.

Distribution.—Aransas, Copano, Matagorda and Galveston Bays; Pascagoula (Mississippi).

91. *Coscinodiscus* sp. 1 (Plate 5, Fig. 91).
A.S.A. (58, 44).

Valves strongly convex; surface with hexagonal areolae concentric to a number of points external to the margin and intersecting; irregular central rosette present.

Distribution.—Matagorda Bay.

92. *Coscinodiscus* sp. 2 (Plate 5, Fig. 92).

Valves strongly convex, with puncta arranged in irregularly parallel rows without secondary arrangement.

Distribution.—Matagorda Bay.

Genus *COSCINOSIRA* Gran, 1900

Frustules in chains united by several filaments emanating well within the margin of the valves; cells drum-shaped, valves flat or rounded.

93. *Coscinosira mediterranea* Schröder (Plate 6, Fig. 93).

Schröder (1911, 628, 5), Hustedt (1927, 318, 156).

Frustule discoid with convex valves and without spines; cells in chains of 2–5, joined by from 2 to 5 strands; valves finely and evenly areolate.

Distribution.—Upper Laguna Madre, Baffin, Corpus Christi, Aransas and Copano Bays.

Genus *COSMIODISCUS* Greville, 1866

Cells solitary, discoid; surface punctate, puncta in radiate rows with hyaline areas between bundles of rows; central area irregular, hyaline with scattered puncta.

94. *Cosmiodiscus elegans* Greville (Plate 6, Fig. 94).

Greville (1866, 79, 13), A.S.A. (1892, 229, 2).

Actinocyclus elegans Karsten (1905, 93, 9, 9).

Coscinodiscus perikompsos Rattray (1890, 576).

Cosmiodiscus beaufortianus Hustedt, 1955.

Frustules in girdle view undulate; valves circular, with a number of rays ending marginally in small tubercles; surface punctate in fasciculate radial rows, varying in number between rays; hyaline areas between fasciculae, at ends of rows of puncta and an irregular hyaline area in center. Resembles *Actinocyclus* except for lack of a pseudocellus. There is considerable variation of form in this species.

Distribution.—Lower Laguna Madre; Pensacola (Florida).

Genus *CYCLOTELLA* Kützing, 1833

Frustules single or in pairs, rarely chains; discoid; valves with undulating or centrally raised surface; marginal areas radially striate.

95. *Cyclotella comta* (Ehr.) Kützing (Plate 6, Fig. 95).

Kützing (1844, 20), Hustedt (1928, 354, 183).

Discoplea comta Ehrenberg (1842, 267).

Cells small with central swelling; striae up to half radius long radial with thickenings between every 2nd or 3rd of the striae; central area punctate in more or less radial rows.

Distribution.—Upper and Lower Laguna Madre, Redfish, Aransas, Matagorda and Galveston Bays (dominant in the last).

96. *Cyclotella kuetzingiana* Thwaites (Plate 6, Fig. 96).

Thwaites (1848, 169), Hustedt (1928, 338, 171).

Cells drum-shaped, tangentially swollen; valves with radial striae from margin up to half cell diameter; central area smooth with scattered puncta.

Distribution.—Galveston and Aransas Bays.

97. *Cyclotella meneghiniana* Kützing (Plate 6, Fig. 97).

Kützing (1844, 50), Boyer (1927, 28), Hustedt (1927, 341, 174).

Cells in girdle view with undulate valve surfaces; valves with center area finely punctate; margin well defined with coarse radiating striae.

Distribution.—Upper and Lower Laguna Madre, Baffin, Aransas, San Antonio, Matagorda, and Galveston Bays.

98. *Cyclotella striata* (Kützing) Grunow (Plate 6, Fig. 98).

Grunow (1880, 119), Hustedt (1927, 344, 176).

Coscinodiscus striatus Kützing, 1844, 131, 1, 8.

Valve surface sinuate; margin with radiate striae; central area with irregular flecks, sinuate valve surface appearing as elongated darker area.

Distribution.—Upper and Lower Laguna Madre, Corpus Christi, Aransas and Matagorda Bays; St. Andrews Bay (Florida).

99. *Cyclotella stylorum* Brightwell (Plate 6, Fig. 99).

Brightwell (1860, 6, 16), Hustedt (1927, 348, 179).

Valves circular, large with strong tangential swelling; marginal zone broad with radial striae and marginal chambers; central area irregularly punctate with lunate or irregular puncta.

Distribution.—Copano and Matagorda Bays; Pascagoula (Mississippi).

Genus *CYMBELLA* Agardh, 1830

Frustules free, stipitate or enclosed in tubes; valve boat-shaped with a curved raphe and one valve margin more gibbous than the other.

100. *Cymbella cistula* (Hemprich) van Heurck (Plate 6, Fig. 100 a).

van Heurck (1885, 64), Boyer (1927, 280).

Cocconema cistula Hemprich in Ehr. (1838, 224); A.S.A. (1875, 10, 24, 25).

Valves arcuate, ventral margin swollen, ends rounded or sub-truncate, terminal nodules reflexed; central area dilated on dorsal side; distinct row of puncta on ventral side of central nodule; striae radial, punctate.

Distribution.—Laguna Madre, Baffin and Corpus Christi Bays.

v. *maculata* (Kützing) Grunow (Plate 6, Fig. 100 b).

Grunow (1884, 45, 1, 8).

Dorsal margin lunate, ventral straight or slightly convex; raphe straight to slightly curved; striae radial at center otherwise transverse.

Distribution.—St. Andrews Bay (Florida).

101. *Cymbella yarrensis* (A.S.) Cleve (Plate 6, Fig. 101).

Cleve (1894, 162).

Encyonema yarrensis A.S.A. (1876, 71, 16).

Cells rectangular in girdle view with rounded ends; in valve view with rounded dorsal and straight ventral margins, slightly rostrate to capitate; raphe almost straight, slightly curved at center; axial area lanceolate, not differentiated from central area; striae transverse, radial at center.

Distribution.—Upper and Lower Laguna Madre, Aransas Bay (common).

Genus *DIATOMA* de Candolle, 1805

Frustules oblong or quadrate, in filaments attached by alternate angles; valves linear to elliptic with transverse costae, rows of puncta and a pseudoraphe.

102. *Diatoma hiemale* (Lyngbye) Heiberg (Plate 6, Fig. 102).

Heiberg (1853, 68), Hustedt (1931, 102, 631).

Fragilaria hiemale Lyngbye (1819, 185).

Cells in girdle view rectangular with rounded ends; girdle bands numerous valves linear to linear-lanceolate, varying in shape; ends rounded, may be produced; transapical ribs coarse, often irregular with striae between; pseudoraphe linear, crossed by ribs. Distribution.—Lower Laguna Madre, Aransas, Matagorda, and Galveston Bays; Carrabelle (Florida).

Genus *DIMEROGRAMMA* Ralfs 1861

Frustules quadrangular raised and hyaline at the corners; chains formed; valves elliptic-lanceolate to linear; pseudoraphe lanceolate; hyaline areas at ends but not in the middle.

103. *Dimerogramma marinum* Ralfs (Plate 6, Fig. 103 a, b).

Ralfs (1861, 790), Boyer (1916, 46, 12, 9–10; 1927, 193).

Valves lanceolate, ends produced; hyaline areas at ends small; pseudoraphe lanceolate; striae consisting of 4 to 5 rows of coarse puncta perpendicular to margin.

Distribution.—Aransas Bay.

104. *Dimerogramma minor* (Gregory) Ralfs (Plate 6, Fig. 104 a-d).

Ralfs (1861, 790), Hustedt (1931, 118, 640, 641).

Denticula minor Gregory (1857, 23, 2, 35).

Frustules in chains or single, in girdle view with undulate valves, ends obliquely produced, valves touching at ends and in the middle; valves bicuneate, apical areas round, hyaline; pseudoraphe linear, may be widened towards middle of valve.

Distribution.—Lower Laguna Madre, Aransas, Copano and Matagorda Bays.

Genus *DIPLONEIS* Ehrenberg, 1840

Valves elliptical to panduriform; raphe enclosed in strong siliceous horns; resembling the lateral areas of *Navicula lyra* but never punctate, central nodule quadrate.

105. *Diploneis bombus* Ehr. (Plate 6, Fig. 105).

Ehrenberg (1844, 84), Hustedt (1937, 704, 1086).

Valves panduriform; central area large, quadrate horns more or less divergent at base, then convergent; longitudinal canal linear; transapical ribs strong, radial, crossed by 2–5 longitudinal ribs parallel to margins.

Distribution.—Upper and Lower Laguna Madre, Corpus Christi, Aransas, Copano, San Antonio, Matagorda and Galveston Bays.

106. *Diploneis chersonensis* (Grunow) Cleve, 1894 (Plate 6, Fig. 106).

Cleve (1894, 91), Hustedt (1937, 709, 1088).

Navicula chersonensis A.S.A. (1875, 12, 40).

Valves panduriform, ends rounded to subacute; central nodule moderate; horns nar-

row, parallel with a row of large puncta; costae strongly marked, radiate crossed by 2 or more usually straight, rarely irregular longitudinal ribs.

Distribution.—Aransas, Copano, and Matagorda Bays.

107. *Diploneis cynthia* (A.S.) Cleve (Plate 6, Fig. 107).

Cleve (1894, 82), Hustedt (1937, 599, 106).

Navicula cynthia A.S.A. (1875, 8, 41).

Valves elliptic to rhombic-elliptic; central area rather small, quadrate; horns parallel; longitudinal canals broad; ribs transverse to radial; loculi unpaired.

Distribution.—Aransas, Copano and Matagorda Bays.

108. *Diploneis fusca* (Gregory) Cleve (Plate 6, Fig. 108).

Cleve (1894, 93), Hustedt (1937, 654, 1053).

Navicula smithii var. *fusca* Gregory (1857, 14, 1, 15).

Valves elliptic to linear-elliptic; central nodule large, subquadrate; horns strongly marked, tapering towards apices, expanded near central area; costae transverse strong, radial to parallel with numerous longitudinal ribs; areolae adjacent to horns in groups of 4 to 5. Most specimens in this region are asymmetric.

Distribution.—Corpus Christi, Aransas, Matagorda and Galveston Bays.

109. *Diploneis gemmatula* (Grunow) Cleve (Plate 6, Fig. 109).

Cleve (1894, 103), Hustedt (1937, 626, 1038).

Navicula gemmatula Grunow in A.S.A. (1875, 13, 20).

Valves linear, sides constricted, ends obliquely rounded; central area small, rounded-quadrate; horns strong, parallel, converging at ends; longitudinal canal broad, linear; striae transverse to radial, loculi with rounded to elliptical pores forming longitudinal lines.

Distribution.—Redfish Bay.

110. *Diploneis ovalis* (Hilse) Cleve (Plate 6, Fig. 110).

Cleve (1891, 44, 2, 13), Hustedt (1937, 671, 1065).

Pinnularia ovalis Hilse in Rabenhorst 1861, 1025.

Navicula ovalis A.S.A. (1875, 7, 33–36).

Valves broadly- to linear-elliptic with convex sides and broadly rounded ends; central area large, variable; horns strong, parallel; longitudinal canal usually narrow; ribs transverse, strong, crossed by somewhat irregular longitudinal lines.

Distribution.—Aransas Bay, Copano Bay.

111. *Diploneis papula* (A.S.) Cleve (Plate 6, Fig. 111).

Cleve (1894, 85), Hustedt (1937, 679, 1071a-c).

Navicula papula A.S.A. (1875, 7, 45–47; 69, 33).

Valves elliptic to linear-elliptic with slightly convex to parallel sides and broadly rounded ends; central nodule small, quadrate; horns strong, divergent at base, convergent at ends; longitudinal canal narrow, lanceolate; striae transverse, slightly radial, crossed by a longitudinal, sub-marginal line.

Distribution.—Aransas and Redfish Bays.

112. *Diploneis smithii* (Brebisson) Cleve (Plate 6, Fig. 112).

Cleve (1894, 96), Hustedt (1937, 647, 1051).

Navicula smithii Breb. in W. Smith (1856, 92).

Valves elliptic; central nodule more or less elliptic, ends truncate; horns parallel on inner, evenly curved on outer edge; costae transverse, radial towards end, separated by 2 rows of areolae, decreasing in size from margin.

Distribution.—Upper Laguna Madre, Aransas, Copano, Matagorda and Galveston Bays.

113. *Diploneis splendida* (Gregory) Cleve (Plate 6, Fig. 113).

Cleve (1894, 87), Hustedt (1937, 712, 1089).

Navicula splendida Gregory, 1856, 44, 5, 14.

Valves panduriform; central area moderate, quadrate to rounded; horns strong, parallel; longitudinal canal broad, linear, slightly constricted at ends; ribs radial, crossed by straight to irregular longitudinal lines farther apart than the transverse ones; a row of pores on the longitudinal canal.

Distribution.—Aransas Bay.

114. *Diploneis weissflogii* (A.S.) Cleve (Plate 6, Fig. 114).

Cleve (1894, 91), Hustedt (1933, 703, 1085).

Navicula weissflogii A.S.A., 1875, 12, 26–32.

Valves constricted in the middle, evenly rounded with round ends; central area small; horns almost parallel, approaching slightly at ends; transapical costae coarse, elongated in the middle, somewhat radial, crossed by several almost straight or slightly irregular longitudinal lines, broken on either side of the central nodule.

Distribution.—Aransas, Copano, San Antonio, Matagorda and Galveston Bays.

Genus *ENDICTYA* Ehrenberg, 1845

Frustules in chains; cylindric; surface areolate; margin with strong teeth.

115. *Endictya oceanica* Ehr. (Plate 6, Fig. 115).

Ehrenberg (1845, 76), Hustedt (1928, 297, 136).

Cells cylindric; valves flat; areolae coarse, slightly diminishing towards margin; corners of areolae papillate; inner mesh finely punctate; margin with fine teeth; mantle areolate.

Distribution.—Matagorda Bay.

Genus *EPITHEMIA* Brebisson, 1838

Cells epiphytic; rectangular in girdle view, sometimes swollen in the middle; valves arcuate with an inner costate and outer punctate strata. It seems logical to unite the genera *Epithemia* and *Rhopalodia* as the distinction is slight and species of both genera are very variable, but to avoid confusion the customary separation will be followed here.

116. *Epithemia argus* (Ehr.) Kütz. (Plate 6, Fig. 116).

Kützling (1844, 35, 29, 55, 56).

Eunotia argus Ehrenberg (1842, 125).

Valves with arcuate dorsal and almost straight ventral margin, ends rounded; costae strong, alternating with more than 2 rows of puncta.

Distribution.—Redfish, Aransas, and Galveston (rare) Bays.

117. *Epithemia zebra* (Ehr.) Kütz. (Plate 6, Fig. 117).

Kützing (1844, 34, 12, 3–5), Boyer (1927, 490).

Navicula zebra Ehrenberg (1833, 262).

Valves with arcuate dorsal and straight ventral margins; ends acute to produced; costae radiate with several rows of puncta between.

Distribution.—Corpus Christi, Aransas and Copano Bays.

Genus *EUNOTIA* Ehrenberg, 1837

Frustules epiphytic, in bundles or single; valves arcuate with transverse striae; raphe rudimentary at terminal nodules, no central nodule.

118. *Eunotia hebridica* A. Berg (Plate 6, Fig. 118).

A. Berg in Cleve Euler (1953, 121, 459).

Valves linear, more or less elongate, slightly curved with parallel sides and capitate ends; terminal nodules large, striae coarse transverse.

Distribution.—Pensacola Bay (Florida).

Genus *EUNOTOGRAMMA* Weisse, 1854

Frustules rectangular; valves elliptic to lunate, divided by septa which constrict the margin.

119. *Eunotogramma laeve* Grunow (Plate 7, Fig. 119).

Grunow in van Heurck (1880–1885, 126, 6, 7, 9, 15).

Frustules rectangular; valves with 2 to 6 pseudosepta, which number may differ on 2 valves of the same cell; one margin straight, the other arcuate.

Distribution.—Matagorda Bay.

120. *Eunotogramma marinum* (W. Smith) Peragallo (Plate 7, Fig. 120 a,b).

Himantidium marinum W. Smith (1857, 10, 2, 14), Hustedt (1955, 10, 4, 10–17).

Frustules rectangular; valves linear to linear-lanceolate with 4 to 18 pseudosepta, one margin straight, the other slightly arcuate.

Distribution.—Matagorda and upper Galveston Bays; Houston.

Genus *EUPODISCUS* Ehrenberg, 1844

Valves circular, areolate with 2 to 4 ocelli but no ridges or processes.

121. *Eupodiscus ovalis* (A.S.) (Plate 7, Fig. 121).

(non Norman, 1861)

A.S.A. (115, 5–7; 1940, 440, 8, 9).

Biddulphia ovalis Boyer (1901, 712).

Valves flat, circular, with fine radiate areolae; ocelli large. Hustedt (1940 l.c.) considers this species close to *Eupodiscus* and in fact it fits this genus better than *Cerataulus*,

Distribution.—Upper Laguna Madre.

122. *Eupodiscus radiatus* Bailey (Plate 7, Fig. 122).

Bailey (1851, 39), A.S.A. (1940, 440, 3–5).

Valves circular, flat, slightly rounded at margins where there are 4 irregularly spaced

ocelli; valve surface with indefinitely arranged, coarse, hexagonal areolae, and a punctate stratum.

Distribution.—Matagorda Bay.

Genus *FRAGILARIA* Lyngbye, 1819

Frustules in ribbons, more or less rectangular; valves lanceolate to cruciform; pseudoraphe variable; striae transverse.

123. *Fragilaria brevistriata* Grunow (Plate 7, Fig. 123).
Grunow (1881, 45, 32, 34).

Cells forming ribbons; valves linear to linear-lanceolate, with bluntly rounded to produced ends; striae short, marginal; pseudoraphe lanceolate, broad.

Distribution.—Matagorda and Aransas Bays.

124. *Fragilaria capucina* Desm. (Plate 7, Fig. 124).
Desm. (1825, *Plants Crypt. France*, 453), Boyer (1927, 187), Hustedt (1931, 144, 659 a-h).

Frustules in long ribbons, linear with blunt ends in girdle view; valves linear with subrostrate apices; striae transverse, marginal.

Distribution.—Laguna Madre, Baffin Bay, Aransas Bay.

125. *Fragilaria construens* (Ehr.) Grunow (Plate 7, Fig. 125).
Grunow (1862, 371, 7, 10), Hustedt (1931, 156, 670a,c).
Staurosira construens Ehrenberg, 1841, 424.

Cells in girdle view rectangular, often very long; valves of very varied shape, lanceolate to cruciform or triangular; striae coarse; pseudoraphe lanceolate.

Distribution.—Baffin Bay.

126. *Fragilaria pinnata* Ehr. (Plate 7, Fig. 126).
Ehrenberg (1841, (1843), 127, 1, 3, 9), Hustedt in A.S.A. (1913, 297, 55–58, 65–72; 298, 47–74).

Valves lanceolate to elliptic-lanceolate with rounded ends, very variable in shape; costae broad, slightly alternate.

Distribution.—Upper Laguna Madre, Corpus Christi Bay, Aransas Bay, Matagorda Bay; Florida coast.

127. *Fragilaria virescens* Ralfs (Plate 7, Fig. 127).
Ralfs (1843, 12, 110), A.S.A. (1913, 297, 3–33), Boyer (1927, 184).

Frustules rectangular, in long ribbons; valves linear to linear-elliptic attenuate at apices, obtuse; transversely striate, punctate; pseudoraphe indistinct, variable.

Distribution.—Lower Laguna Madre.

Genus *FRUSTULIA* Agardh, 1824 em. Grunow, 1865

Valves naviculoid; raphe between two thickened, hyaline ribs; central and terminal nodules frequently elongate; valve surface with longitudinal and transverse lines.

128. *Frustulia interposita* (Lewis) de Toni (Plate 7, Fig. 128 a,b).
de Toni (1891, 278), Hustedt (in A.S.A. 1930, 369, 10).

Navicula interposita Lewis (1865, 2, 19).

Valves linear-elliptic with broadly rounded ends; axial ribs strong; central pores of raphe distant; central area symmetrical (differing from that shown by Hustedt (l.c.); longitudinal and transverse network of valve surface regular except near central area.

Distribution.—Aransas Bay.

129. *Frustulia rhomboides* (Ehrenberg) de Toni (Plate 7, Fig. 129a).

de Toni (1891, 277), Hustedt (1937, 728, 1098).

Navicula rhomboides Ehrenberg (1841, 3, 15).

Valves rhombic to lanceolate with rounded ends; raphe with central nodules distant, axial ribs strong; longitudinal and transverse network of valve surface regular except for central area.

Distribution.—Aransas Bay.

v. *saxonica* (Rabenhorst) de Toni (Plate 7, Fig. 129 b).

de Toni (1891, 277), Hustedt (1937, 729, 1099).

Valves elliptic-lanceolate, ends more or less produced.

Distribution.—Laguna Madre.

Genus *GRAMMATOPHORA* Ehrenberg, 1840

Frustules rectangular; forming zig-zag chains; valves lanceolate with gibbous center; septa two, usually slightly sigmoid.

130. *Grammatophora maxima* Grunow (Plate 7, Fig. 130).

Grunow (1862, 416, 8, 5), Hustedt (1933, 44, 572).

Frustules with coarse septa, rather coarser than in *G. marina*; valve surface finely areolate; valves linear, slightly gibbous, pseudoraphe narrow.

Distribution.—Lower Laguna Madre.

131. *Grammatophora marina* (Lyngbye) Kützing (Plate 7, Fig. 131 a,b).

Kützing (1884, 17, 24), Boyer (1927, 56.)

Diatoma marinum Lyngbye (1819, 180, 62).

Cells in zig-zag chains or single; frustules in girdle view rectangular, with rounded ends, in valve view linear or linear-elliptic; internal septa straight or curved near margin with knobbed ends; valve surface areolate.

Distribution.—Laguna Madre, Corpus Christi, Aransas and San Antonio Bays.

132. *Grammatophora oceanica* Ehr. (Plate 7, Fig. 133).

Ehrenberg (1854), Hustedt (1931, 45, 573–4).

Cells solitary or in zig-zag chains; frustules in girdle view linear-oblong; septa appear H-shaped near margin, linear with knobbed ends; valves lanceolate, ends may be slightly capitate; striae very faint.

Distribution.—Laguna Madre, Corpus Christi and Aransas Bays.

Genus *HANTZSCHIA* Grunow, 1877

Valves bean-shaped with rostrate ends; keel puncta short, raphe lateral on keel; surface of valve striate.

133. *Hantzschia amphioxys* (Ehr.) Grunow.

Grunow (1880, 103), A.S.A. (1930, 329, 11, 12, 15, 20).

Eunotia amphioxys Ehrenberg, 1841, 25, 1, 26.

Valves slightly arcuate with capitate apices; keel puncta irregular; striae transverse.

v. compacta Hustedt (Plate 7, Fig. 133).

Hustedt in A.S.A. (1930, 345, 11).

Frustule broader than type, valve more sinuate; striae transverse.

Distribution.—Florida Gulf coast.

134. *Hantzschia marina* (Donkin) Grunow (Plate 7, Fig. 134).

Grunow (in Cleve & Grunow, 1880, 105), Boyer (1916, 114, 32, 22).

Epithemia marina Donkin (1858, 29, 3, 14).

Valve bean-shaped, capitate, with dorsal margin slightly arcuate, ventral straight; keel puncta prolonged into striae across valve; separated by puncta.

Distribution.—Upper Laguna Madre, Aransas Bay.

Genus *HUTTONIA* Grove & Sturt, 1887

Frustules rectangular; valves twisted on perivalvar axis; ocelli on blunt processes within valve margin.

135. *Huttonia reichardtii* Grunow (Plate 7, Fig. 135).

Grunow (1888, 39), Hustedt (1929).

Cells equidimensional in girdle view with sinuate girdle and processes set at an angle, within valve corners; valves circular but irregularly depressed near ocelli; valve and girdle surface areolate.

Distribution.—Copano and Matagorda Bays.

Genus *LICMOPHORA* Agardh, 1827

Frustules cuneate, stipitate, often forming more or less branched, fan-shaped colonies; septate; valves cuneate with rounded or capitate distal ends, proximal end acute.

136. *Licmophora flabellata* (Carmichael) Agardh (Plate 7, Fig. 136).

Agardh (1830–1832, 41), Boyer (1927, 165), Hendey (1951, 39, 16, 1, 2, 12).

Cells frequently attached basally to a branched stipe, up to 20 cells per stipe; frustule in girdle view cuneate, with numerous septa penetrating from upper part of cell; valves cuneate-lanceolate to clavate; base slightly swollen; faintly striate.

Distribution.—Aransas Bay, rare in muds.

Genus *LITHODESMIUM* Ehrenberg, 1840

Frustules prismatic, chain forming; attached by persistent girdle bands and a central spine; valves triangular, undulate with raised center and 3 marginal processes.

137. *Lithodesmium undulatum* Ehr. (Plate 7, Fig. 137).

Ehrenberg (1840, 75, 4, 13), Hustedt (1930, 789, 461).

Frustules prismatic, in chains; valves with central spine, undulate with 3 raised terminal processes; surface with radial puncta.

Distribution.—Copano Bay, Matagorda Bay (normally a planktonic species).

Genus *MASTOGLOIA* Thwaites, 1856

Frustules rectangular; valves naviculoid; surface with transverse and diagonal or longitudinal lines; a loculiferous plate between valve and girdle.

138. *Mastogloia acutiuscula* Grunow (Plate 7, Fig. 138 a,b).

Grunow (1883, 495), Hustedt (1931–1933, 515, 947).

Valves linear-lanceolate with acutely rounded ends; raphe straight, between 2 coarse, longitudinal ribs; surface with transverse ribs; loculi even, numerous, not reaching ends.

Distribution.—Upper Laguna Madre.

139. *Mastogloia angulata* Lewis (Plate 7, Fig. 139).

Lewis (1861, 65), Boyer (1927, 334), Hustedt (1931–1933, 465, 885).

Valves elliptic with slightly produced ends; loculi numerous, two or three larger loculi in the middle; axial area narrow; central area small, may be almost absent; striae punctate in rows parallel to transverse axis.

Distribution.—Upper Laguna Madre, Aransas Bay.

140. *Mastogloia apiculata* W. Smith (Plate 7, Fig. 140, a,b).

W. Smith (1856, 65), Hustedt (1931–1933, 515, 946).

Valves elliptic-lanceolate, sometimes produced; raphe straight, enclosed between 2 longitudinal ribs; central area very small; striae transverse to slightly radiate, punctate; puncta in longitudinal rows; loculi small, even, almost reaching ends of valves.

Distribution.—Upper and Lower Laguna Madre, Corpus Christi, Aransas and Galveston Bays; St. Andrews Bay (Florida).

141. *Mastogloia asperula?* Grunow (Plate 7, Fig. 141).

Grunow (1892, 23, 12), Hustedt (1933, 480, 901).

Valves elliptic-lanceolate with rostrate ends; raphe straight to sinuate; axial area very narrow; central area small, round; surface areolate, forming a network of crossing systems; areolae hexagonal; loculi small, even, reaching apex.

Distribution.—Aransas Bay.

142. *Mastogloia baldjikiana* Grunow (Plate 7, Fig. 142).

Grunow (in A.S.A., 1893, 188, 1, 2), Hustedt (1931–1933, 550, 981).

Valves rounded, elliptic or elongate with rounded to subrostrate ends; raphe straight or excavated; axial area very narrow; central area widened to form two longitudinal furrows; valve surface with transverse costae crossed by faint longitudinal ridges; loculi even, about 10, not reaching ends.

Distribution.—Upper and Lower Laguna Madre, Aransas and Copano Bays, Florida Gulf Coast.

143. *Mastogloia binotata* (Grunow) Cleve (Plate 7, Fig. 143).

Cleve (1895, 148), Hustedt (1931–1933, 470, 889).

Orthonais binotata Grunow, 1867, 15.

Valves broadly elliptic with evenly rounded ends; raphe straight; axial area very

narrow; central area transverse, sagittate; valve surface areolate, areolae forming an even network; one long loculus on either side, with inner margin straight.

Distribution.—Lower Laguna Madre.

144. *Mastogloia braunii* Grunow (Plate 8, Fig. 144).

Grunow (1863, 156, 4, 2), Hustedt (1931–1933, 551, 982).

Valves lanceolate with tapering or slightly produced ends; raphe strongly curved; axial area narrow, central area large, rectangular, extending into H-shaped extensions towards apices; loculi rectangular, numerous, some enlarged; not reaching ends; puncta in transverse rows; longitudinal rows narrower than transverse.

Distribution.—Upper Laguna Madre.

145. *Mastogloia chersonensis* A.S. (Plate 8, Fig. 145 a,b).

A.S.A. (1893, 186, 31, 32), Hustedt (1931–1933, 565, 999).

Valves linear-elliptic to linear-lanceolate, almost rhombic, with broadly rounded ends; raphe sinuate, axial area narrow; surface with transverse, slightly radial striae, longitudinal interrupted lines; loculi small, numerous, narrowest in the middle.

Distribution.—Redfish Bay.

146. *Mastogloia cocconeiformis* Grunow (Plate 8, Fig. 146).

Grunow (1860, 578, 7, 13), Hustedt (1931–1933, 469, 888).

Valves elliptic, almost circular; raphe slightly curved; axial area very narrow; central area small, circular to elliptic; valves with even, hexagonal areolae forming a threefold system; loculi narrow, numerous, reaching apices.

Distribution.—Aransas Bay.

147. *Mastogloia cribrosa* Grunow (Plate 8, Fig. 147).

Grunow (1860, 577, 5, 10c), Hustedt (1931–1933, 468, 887).

Cells solitary, often enclosed in a gelatinous sheath; valves broadly elliptic; central nodule small, raphe straight; areolae transverse, regular; loculi numerous, reaching apex.

Distribution.—Upper and Lower Laguna Madre, Aransas Bay.

148. *Mastogloia crucicula* (Grunow) Cleve (Plate 8, Fig. 148 a,b).

Cleve (1895, 148), Hustedt (1955, 19, 6, 12).

Orhoneis crucicula Grunow (1877, 177, 195, 8).

Valves elliptic, ends rounded to acute; raphe straight; axial area narrow, straight; central area transverse, forming a stauros; areolae in radiate rows, loculi 4 on each side, elongate.

Distribution.—Aransas Bay.

149. *Mastogloia erythraea* Grunow (Plate 8, Fig. 149).

Grunow (1860, 577, 7, 4).

Mastogloia interrupta Hantzsch in Rabenhorst (1863, 20, 6a, 5a,b), A.S.A. (196, 37).

Valves lanceolate to rhombic lanceolate with more or less produced acute ends; raphe

sinuate, areas narrow; surface transversely striate, longitudinal lines present; loculi small in the middle and at the ends, larger between.

Distribution.—Aransas Bay.

150. *Mastogloia horvathiana* Grunow (Plate 8, Fig. 150).

Grunow (1860, 578, 7, 13), A.S.A. (188, 41), Hustedt (1931–33, 471, 890).

Valves broadly elliptic; raphe curved; axial area very narrow; central area small; valve surface evenly areolate, forming radiate and concentric systems; loculi numerous, narrow, reaching apices.

Distribution.—Upper Laguna Madre.

151. *Mastogloia labuensis* Cleve (Plate 8, Fig. 151).

Cleve in A.S.A. (1893, 187, 2), Hustedt (1931–33, 578, 950).

Valves linear, sides parallel, ends acute, slightly produced; raphe straight; axial area straight, central area elliptic; striae transverse with irregular longitudinal lines; loculi numerous, even, not reaching apex.

Distribution.—Upper Laguna Madre.

152. *Mastogloia lanceolata* Thwaites (Plate 8, Fig. 152 a,b).

Thwaites in W. Smith (1856, 64, 54, 340), Hustedt (1931–33, 497, 922).

Valves lanceolate with bluntly rounded or slightly produced ends; raphe slightly curved in the middle; axial area very narrow, central area small, circular; valve surface with transverse and irregular longitudinal striae; loculi numerous, not reaching apices.

Distribution.—Aransas Bay, dominant at one station in Lower Laguna Madre.

153. *Mastogloia latericia* (A.S.) Cleve (Plate 8, Fig. 153).

Cleve (1895, 162).

Orhoneis latericia A.S.A. (1893, 188, 40).

Valves elliptic with acute ends; raphe straight, axial and central areas narrow; areolae in transverse rows forming irregular longitudinal pattern; loculi rectangular, not reaching apex.

Distribution.—Aransas Bay.

154. *Mastogloia pumila* (Grunow) Cleve (Plate 8, Fig. 154 a,b,c).

Cleve (1895, 157), Hustedt (1931–33, 553, 983).

M. braunii v. *pumila* Grunow, in van Heurck (1880–85, 4, 23).

Valves linear-lanceolate with tapering, rounded ends; raphe straight; axial area narrow; central area rectangular, extended apically to form an H-shaped lateral area; strong radial ribs on transverse axis, longitudinal lines fine; loculi 6 to 8, one to three in the middle larger, not reaching ends.

Distribution.—Upper Laguna Madre; Fort Pike (Mississippi).

155. *Mastogloia pusilla* Grunow (Plate 8, Fig. 155).

Grunow (1878, 111, 3, 11), Hustedt (1931–33, 568, 1002a-c).

Valves linear-elliptic with lanceolate to rounded or slightly produced ends; raphe

straight, areas very narrow; striae transverse, crossed by slightly closer longitudinal striae; central loculi larger, loculi not reaching ends.

Distribution.—Upper Laguna Madre, Corpus Christi and Aransas Bays; St. Joe's (Florida).

156. *Mastogloia quinquecostata* Grunow (Plate 8, Fig. 156).

Grunow (1860, 578, 7, 8), Hustedt (1931–33, 556, 989).

Valves linear-elliptic with acute ends; raphe undulate; axial area narrow; loculi 18–20 almost reaching apices; valve surface with punctate, transverse striae, with irregular longitudinal arrangements; on each side of raphe are several longitudinal depressions which lack striae.

Distribution.—Lower Laguna Madre.

157. *Mastogloia smithii* Thwaites (Plate 8, Fig. 157).

Thwaites (in W. Smith, 1856, 65, 54, 341), Boyer (1916, 87, 17, 19), Hustedt (1931–33, 502, 928a).

Frustules in valve view elliptic-lanceolate, ends slightly produced; raphe straight; axial area narrow, central area small, round; striae transverse, punctate, forming longitudinal lines; loculi usually 6–9, not reaching apices.

Distribution.—Upper Laguna Madre, Aransas Bay.

158. *Mastogloia subaffirmata* Hustedt (Plate 8, Fig. 158 a, b).

Hustedt in A.S.A. (1927, 368, 13; 1931–1933, 526, 960a-f).

Valves broadly elliptic to rhombic lanceolate with produced, sharp ends; raphe strongly curved, narrow; areas narrow, following raphe; surface with transapical striae crossed by irregular longitudinal lines; loculi numerous, small.

Distribution.—Lower Laguna Madre.

Genus *MELOSIRA* Agardh, 1824 em. de Toni, 1892

Frustules cylindrical to globose, attached by valve ends to form straight chains; furrow between valve and girdle usually evident.

159. *Melosira granulata* (Ehrenberg) Ralfs (Plate 8, Fig. 159).

Ralfs (in Pritchard, 1861), Hustedt (1927, 248, 104).

Gallionella granulata Ehrenberg (1843, 170).

Frustules in chains, may be slender, elongate, broad or short, with wide, clear apertures between alternate cells; puncta more or less spiral, may be large or small; a variable form.

Distribution.—Corpus Christi, Redfish and Galveston Bays; Pascagoula (Mississippi).

160. *Melosira nummuloides* (Dillwyn) Agardh (Plate 8, Fig. 160).

Agardh (1824, 8), Hustedt (1927, 231).

Conferva nummuloides Dillwyn (1809, 43).

Frustules spherical to cylindric-elliptic with flattened apices and cylindrical mantle; valve surface punctate with radial margin.

Distribution.—Upper Laguna Madre, Corpus Christi, Aransas and Matagorda Bays.

161. *Melosira ornata* Grunow (Plate 8, Fig. 161).

Grunow (1884, 95, 39, 40), Hustedt (1927, 274, 117).

Frustules in cylindrical chains with low mantle; valves flat, walls strong with a fine, threefold pore arrangement and a series of inwardly open chambers around the margin, internally concentric markings and irregularly arranged puncta.

Distribution.—Aransas Bay.

162. *Melosira setosa* Greville (Plate 8, Fig. 162).

Greville (1866, 436, 6, 17–19), A.S.A. (182, 42–46).

Frustules in short chains, subspherical; valves with rounded margins, evenly areolate with a mat of setae on somewhat flattened valves.

Distribution.—Upper Laguna Madre, Baffin Bay, Matagorda Bay.

163. *Melosira sulcata* (Ehr.) Kützing (Plate 8, Fig. 163).

Kützing (1844, 55, 2, 7), Hustedt (1927, 276, 119).

Frustules usually in short chains or single, thick walled, discoid with robust margin and coarsely granulate surface in girdle view; valves with strongly reinforced margin and rays extending a variable distance towards center which is usually hyaline.

Distribution.—Upper Laguna Madre, Baffin, Aransas, San Antonio, Espiritu Santo, Matagorda and Galveston Bays.

Genus *NAVICULA* Bory, 1826

Valves linear to elliptic, ends variable, raphe straight, axial area usually distinct; central area may be small or extended into lyrate lateral areas; striae transverse to radiate, punctate.

164. *Navicula ambigua* Ehr. (Plate 8, Fig. 164).

Ehrenberg (1842, 2, 9), A.S.A. (211, 42–47).

Valves elliptic-lanceolate with capitate ends; axial and central areas narrow; striae transverse; frustule craticulate.

Distribution.—Aransas, San Antonio, and Galveston Bays; Pensacola Bay (Florida).

165. *Navicula clavata* Gregory (Plate 9, Fig. 165).

Gregory (1856–7, 46, 5, 17), A.S.A. (1876, 70, 50), Boyer (1927, 415).

Valves elliptic; lateral areas semi-lanceolate, ends diverging, interrupting the transverse punctate striae.

Distribution.—Aransas and Matagorda Bays.

166. *Navicula delawarensis* Grunow (Plate 9, Fig. 166).

Grunow (1891, 13, 1, 8, 7), Boyer (1916, 92, 25, 3; 1927, 406), A.S.A. (244, 10, 11).

Valves elliptic with produced apices; axial area narrow, central area slightly bilobed; striae fairly coarse, radiate, punctate.

Distribution.—Aransas Bay.

167. *Navicula directa* (W. Smith) Ralfs (Plate 9, Fig. 167).

Ralfs (1861, 906), A.S.A. (1875, 47, 1-5), Boyer (1927, 395).

Valves elongate-lanceolate, ends acute; axial and central areas narrow, even; striae coarse transverse, parallel.

Distribution.—Laguna Madre, Baffin, Aransas and Matagorda Bays.

168. *Navicula distans* (W. Smith) Ralfs (Plate 9, Fig. 168).

Ralfs (1861, 907), A.S.A. (1878, 46, 11-14).

Pinnularia distans W. Smith, 1853, 56, 18, 169.

Valves linear-lanceolate with acutely rounded ends; raphe curved; axial area narrow, even; central area wide, oblong, bounded by 2 or 3 very short striae; striae coarse, punctate, radiate.

Distribution.—Baffin, Matagorda and Aransas Bays.

169. *Navicula diversistriata* Hustedt (Plate 9, Fig. 169 a,b).

Hustedt (1955, 28, 9, 6-9).

Valves elliptic-lanceolate with acute, subrostrate ends; axial area narrow-lanceolate somewhat dilated between apical and terminal nodules; structure of 2 valves different, in one the central area is dilated, in the other not; striae radiate in the former, transverse in the latter.

Distribution.—Baffin, Galveston and Aransas Bays.

170. *Navicula forcipata* Greville (Plate 9, Fig. 170).

Greville (1859, 83, 6, 10-11), A.S.A. (1876, 70, 18).

Valves elliptic to linear-elliptic; surface striate, punctate; striae transverse, interrupted by hyaline lateral areas constricted in the middle and at the ends; axial area dilated at central nodules.

Distribution.—Upper Laguna Madre, Corpus Christi, Aransas and Matagorda Bays.

171. *Navicula granulata* Bailey (Plate 9, Fig. 171).

Bailey (1853, 7, 10), Boyer (1927, 404).

Valves elliptic-lanceolate, broad; axial area may be straight or lanceolate; central area round; striae at right angles to margin, punctate, often irregular towards center. Hustedt (1955) rightly unites *N. brasiliensis* with *N. granulata*; both forms and intergrades are common in the Texas material.

Distribution.—Laguna Madre, Aransas, San Antonio and Matagorda Bays; Pensacola Bay (Florida).

172. *Navicula grevillei* Agardh (Plate 9, Fig. 172).

Agardh (1830, 18), Cleve (1894, 152).

Valves elliptic-lanceolate with obtuse ends; axial area indistinct; central area small; striae closer at the ends, the 4-5 median striae being more radiate than the others. Frustules often encased in a mucilaginous tube (*Schizonema*).

Distribution.—Laguna Madre.

173. *Navicula hummii* Hustedt (Plate 9, Fig. 173).

Hustedt (1955, 23, 8, 8-10, 24).

Valves broadly elliptic; raphe straight with terminal nodules distant from the ends, central pores distant; axial area wide, contracted at middle and at ends; central area forming a stauros and bow-shaped lateral areas separated from the axial area by a row of coarse puncta; striae punctate at right angles to lateral area.

Distribution.—Lower Laguna Madre, Aransas Bay.

174. *Navicula impressa* Grunow (Plate 9, Fig. 174).

Grunow in A.S.A. (1875, 6, 17, 18, 36), Boyer (1927, 407).

Valves broadly lanceolate, sides parallel, slightly constricted in the middle, ends acute rostrate; axial area narrow; central area slightly dilated; striae transverse, central ones may be interrupted; punctate.

Distribution.—Upper Laguna Madre.

175. *Navicula longa* Gregory (Plate 9, Fig. 175).

Gregory (1856, 47, 5, 18), Ralfs (1861, 906), Boyer (1916, 27, 20; 1927, 297).

Valves linear-lanceolate, elongate; axial and central areas small; striae coarse, radiate.

Distribution.—Corpus Christi Bay.

176. *Navicula nummularia* Greville (Plate 9, Fig. 176).

Greville (1859, 249, 5, 6), Hustedt (1955, 22, 7, 15, 16).

Valves elliptical to circular; raphe straight, axial area narrow, central area extended, the lateral areas forming an 8; striae coarse, radiate with puncta between.

Distribution.—Lower Laguna Madre.

177. *Navicula peregrina* (Ehr.) Kützing (Plate 9, Fig. 177).

Kützing (1844, 97, 28, 52), Boyer (1916, 94, 26, 20; 1927, 339).

Pinnularia peregrina Ehrenberg (1844, 133).

Frustules in valve view linear-lanceolate with abruptly rounded ends; central area oval or rectangular, larger on one side; striae radiating at center, otherwise at right angles to margin.

Distribution.—Aransas Bay.

178. *Navicula pseudobacillum* Grunow (Plate 9, Fig. 178).

Grunow (1880, 45, 2, 52), Cleve (1894, 137).

Valves linear-elliptic with rounded ends; terminal nodules expanded laterally; axial area narrow, raphe broad; central area small; striae more distant in the middle than at the ends, radial, finely punctate.

Distribution.—Carrabelle (Florida).

179. *Navicula punctigera* Hustedt (Plate 9, Fig. 179).

Hustedt (1955, 26, 7, 4).

Valves broadly elliptic, raphe straight; axial area lanceolate, rather large; central area irregular, somewhat transapically dilated; striae radiate, distinctly punctate, some shorter striae in middle of valve.

Distribution.—Matagorda Bay.

180. *Navicula rostellata* Kützing (Plate 9, Fig. 180).

Kützing (1844, 95, 3, 65), A.S.A. (1876, 47, 31).

Valves elliptic-lanceolate with rostrate ends; axial and central areas narrow; striae coarse, radiating at center, transverse at ends.

Distribution.—Aransas Bay.

181. *Navicula ruttneri* Hustedt (Plate 9, Fig. 181).

Hustedt in A.S.A. (1936, 402, 30–52).

Valves lanceolate with broadly rounded ends, sometimes produced to capitate; raphe straight; central nodules prominent; axial area narrow-lanceolate; striae coarse with central area dilated; one or two short striae irregularly spaced in central region.

Distribution.—Aransas Bay, Carrabelle (Florida).

182. *Navicula seductilis* A.S. (Plate 9, Fig. 182).

A.S.A. (1875, 2, 35).

N. lyra v. *seductilis* Cleve (1895, 64).

Valves linear-elliptic, ends rounded, acute; raphe straight; axial area narrow; central area extended longitudinally forming an H about half cell width, tapering to apices; striae relatively coarse, punctate. The lateral areas are not lyrate as in *N. lyra* and there seems no reason for following Cleve in retaining this among the too numerous *N. lyra* forms.

Distribution.—Aransas Bay.

183. *Navicula spuria* Cleve (Plate 9, Fig. 183).

Cleve (1895, 31), Peragallo (1908, 12, 5).

Valves narrow-lanceolate, acute; axial area very narrow; central area small, striae radiate in the middle, parallel at ends.

Distribution.—Corpus Christi Bay.

184. *Navicula subcarinata* Hendey (Plate 9, Fig. 184).

Hendey (1951, 50, 10, 2, 3).

N. lyra v. *subcarinata* Grunow in A.S.A. (1875, 2, 5).

Cells solitary; valves elliptical with somewhat rostrate ends; in girdle view, axial area elevated, particularly at ends.

Distribution.—Lower Laguna Madre, Matagorda Bay; Pensacola (Florida).

185. *Navicula subdiffusa* Hustedt (Plate 9, Fig. 185).

Hustedt (1955, 24, 8, 22).

Valves broad, linear with cuneate or produced ends; raphe straight with hooked terminal pores; axial area linear-lanceolate; central area dilated; striae at right angles to margins, punctate, puncta closer near margins otherwise tend to be irregular.

Distribution.—Aransas Bay.

186. *Navicula viridula* Kützing (Plate 9, Fig. 186).

Kützing (1844, 91, 30, 47), Cleve (1895, 16), Peragallo (1908, 12, 21, 24).

Valves lanceolate with produced apices; axial and central areas narrow, striae parallel, slightly radiate at center.

Distribution.—Baffin, Aransas, Copano and Galveston Bays.

187. *Navicula weissflogii* (Grunow) Cleve (Plate 9, Fig. 187).

Cleve (1894, 152), Boyer (1927, 375), A.S.A. (1934, 397, 42).

Brebissonia weissflogii Grunow in Cleve, 1878, 7, 10.

Valves rhomboid with obtuse ends; raphe with distinct median and terminal pores; axial area indistinct, central area elongate; striae transverse in the middle, radiate at ends, punctate, puncta forming undulate longitudinal rows.

Distribution.—Lower Laguna Madre, Aransas, Copano and San Antonio Bays.

188. *Navicula yarrensis* Grunow (Plate 9, Fig. 188).

Grunow (in A.S.A., 1876, 46, 1–6), Boyer (1927, 418).

Valves elliptic-lanceolate with acute ends; axial area narrow, widened centrally; striae radiate in the middle, slightly convergent and closer at ends.

Distribution.—Laguna Madre, Corpus Christi, Copano, Matagorda and Galveston Bays; Florida Gulf.

189. *Navicula zostretii* Grunow (Plate 10, Fig. 189).

Grunow (1860, 528, 4, 23), A.S.A. (1875, 47, 42–44).

Valves elongate-lanceolate with rounded, acute ends; raphe straight; axial and central areas narrow; striae coarse, radiate.

Distribution.—Laguna Madre, Corpus Christi and Matagorda Bays; associated with *Diplanthera* in the Cut, Laguna Madre.

190. *Navicula elegans* W. Smith (Plate 10, Fig. 190).

W. Smith (1853, 1, 49), Boyer (1916, 31, 2; 1927, 418).

Valves broadly elliptic-lanceolate with cuneate ends; raphe straight; axial area narrower in the middle and at ends, central area slightly dilated; striae consisting of rows of rectangular puncta at an angle to line of striae; striae radiate, closer at center and at ends.

Distribution.—Aransas Bay.

Genus *NITZSCHIA* Hassel, 1845 em. Grunow, 1880

Frustules free, enclosed in sheath or in filaments; valves with keel bearing the raphe, keels diagonally opposite; keel puncta variable.

191. *Nitzschia acicularis* (Kützing) W. Smith (Plate 10, Fig. 191 a,b).

W. Smith (1853, 43, 15, 122), A.S.A. (1921, 335, 13–17).

Synedra acicularis Kützing (1844, 63, 4, 3).

Valves aciculate lanceolate, with awns about the length of the median part; striae fine, keel puncta even.

Distribution.—Matagorda Bay.

192. *Nitzschia constricta* Ralfs (Plate 10, Fig. 192).

Ralfs (in Pritchard, 1861, 780), A.S.A. (1921, 333, 18).

Valves slightly constricted in the middle with rounded and slightly produced ends; central fold marked; valve surface punctate in transverse rows but forming an hexagonal pattern; keel puncta coarse, even.

Distribution.—Matagorda Bay.

193. *Nitzschia distans* Gregory (Plate 10, Fig. 193 a, b).

Gregory (1857, 58, 6, 103), Hustedt (1921 in A.S.A., 334, 1, 2), Boyer (1927, 512).

Valves linear-lanceolate, with acute, tapering ends; striae fine, transverse, keel puncta irregular, more distant towards ends.

Distribution.—Aransas Bay.

194. *Nitzschia gracilis* Hantzsch (Plate 10, Fig. 194).

Hantzsch (1859, 40, 6–8), Hustedt in A.S.A. (1924, 349, 34–37).

Valves fusiform, slender, slightly sigmoid; striae somewhat coarse, marginal longitudinal fold more or less hyaline; keel puncta regular, conspicuous.

Distribution.—Laguna Madre, Aransas Bay, Matagorda Bay.

195. *Nitzschia granulata* Grunow (Plate 10, Fig. 195).

Grunow (1880, 395, 12, 7), A.S.A. (1924, 330, 4–9), Boyer (1927, 496).

Valves elliptic to semi-lanceolate; striae in double rows on keel margin; puncta on valve surface in transverse rows, large, more distant in center.

Distribution.—Upper Laguna Madre, Aransas Bay, San Antonio Bay.

196. *Nitzschia hungarica* Grunow (Plate 10, Fig. 196).

Grunow (1862, 568, 12, 31), A.S.A. (1924, 331, 6–13), Boyer (1927, 498).

Valves linear-lanceolate narrower in the center, ends rostrate; longitudinal fold marked; striae transverse, coarse; keel puncta coarse.

Distribution.—Lower and Upper Laguna Madre, San Antonio, Matagorda, Baffin, Aransas and Galveston Bays; Pensacola Bay, Florida.

197. *Nitzschia longissima* (Brebisson) Ralfs (Plate 10, Fig. 197).

Ralfs in Pritchard (1861, 783).

Ceratoneis longissima Brebisson in Kützing (1849, 891).

Cells solitary; frustules spindle-shaped with long, usually curved awns; keel puncta even; one chromatophore extending into awns.

Distribution.—Aransas and Matagorda and Galveston Bays.

198. *Nitzschia lorenziana* Grunow (Plate 10, Fig. 198 a,b).

Grunow (in Cleve & Grunow, 1880, 101), Boyer (1927, 524).

Valves narrow, fusiform, sigmoid with ends pointing in opposite directions, blunt; keel puncta irregular, the two median distant; striae distant in the middle, closer at ends.

Distribution.—Laguna Madre, Aransas Bay, Matagorda Bay.

199. *Nitzschia mediterranea* Hustedt (Plate 10, Fig. 199).

Hustedt in A.S.A. (1921, 331, 22).

Valves broad, constricted in the middle, with obtuse, produced ends; raphe excentric; keel puncta marked; fold strong; surface punctate, puncta in diagonal, transverse and longitudinal arrangement.

Distribution.—Upper Laguna Madre, Aransas and Matagorda Bays.

200. *Nitzschia obtusa* W. Smith (Plate 10, Fig. 200 a,b).

W. Smith (1853, 39, 13, 109), Boyer (1916, 121, 39, 16; 1927, 516), A.S.A. (1921, 336, 20, 21, 352, 6, 7).

Valves sigmoid, sides straight, curved oppositely at the ends; keels excentric; inflexed in the middle; two median keel puncta distant.

Distribution.—Laguna Madre, Galveston Bay; Pensacola (Florida).

201. *Nitzschia palea* (Kützing) W. Smith (Plate 10, Fig. 201).

W. Smith (1856, 99), Boyer (1916, 122, 32, 15; 1927, 521), A.S.A. (1924, 349, 1–10). *Synedra palea* Kützing) W. Smith (Plate 10, Fig. 201).

Valves linear-lanceolate, ends slightly rostrate; striae very fine, keel puncta regular.

Distribution.—Lower and Upper Laguna Madre, Baffin and Galveston Bays.

202. *Nitzschia panduriformis* Gregory (Plate 10, Fig. 202 a,b).

Gregory (1857, 529, 14, 102), Hustedt in A.S.A. (1924, 331, 19, 21).

Valves panduriform, apices acute; longitudinal fold marked; striae transverse and oblique; keel puncta coarse.

Distribution.—Lower Laguna Madre, Aransas, Corpus Christi and Matagorda Bays.

203. *Nitzschia plana* W. Smith (Plate 10, Fig. 203).

W. Smith (1853, 42, 15, 114), Boyer (1916, 117, 32, 2; 1927, 500), A.S.A. (1924, 330, 3).

Valves linear, slightly constricted in the middle; apices acute, may be slightly produced; longitudinal fold marked, distant from keel; striae irregular, interrupted; keel puncta strong, oblong.

Distribution.—Aransas and Galveston Bays.

204. *Nitzschia punctata* (W. Smith) Grunow (Plate 10, Fig. 204).

Grunow in Cleve & Grunow (1880, 69), A.S.A. (1924, 330, 10–14).

N. compressa Boyer (1916, 116, 39, 7; 1927, 496).

Valves elliptic-lanceolate with produced ends; striae transverse, coarsely punctate; longitudinal line broad; keel puncta regular.

Distribution.—Laguna Madre, Aransas, Matagorda and Galveston Bays.

205. *Nitzschia sigma* (Kützing) W. Smith (Plate 10, Fig. 205).

W. Smith (1853, 39, 13, 108), Boyer (1916, 121, 39, 13; 1927, 514).

Synedra sigma Kützing (1844, 67).

Valves linear, ends sigmoid, tapering to the subacute ends; keel excentric; striae fine, punctate.

Distribution.—Laguna Madre, Aransas, Matagorda and Galveston Bays.

206. *Nitzschia silicula* Hustedt, 1955 (Plate 10, Fig. 206).

Hustedt (1955, 14, 16, 19, 20).

Valves lanceolate with very slightly rostrate, subacute ends; fold slight; keel excentric; keel puncta indistinct; transverse striae crossed by longitudinal striae.

Distribution.—Laguna Madre, Baffin, Aransas, San Antonio and Galveston Bays; St. Andrews Bay (Florida).

207. *Nitzschia tryblionella* Hantzsch

Hantzsch (1859, in Rabenhorst, 984), A.S.A. (1921, 332, 14), Boyer (1916, 116, 32, 8; 1927, 495).

Valves elliptic-lanceolate with subacute ends; longitudinal fold well marked; keel very excentric; striae coarse, transverse, puncta between striae indistinct.

v. *victoriae* (Grunow) van Heurck (Plate 10, Fig. 207).

Grunow in Cleve & Grunow (1880, 69).

Valves broad, sometimes slightly constricted, ends cuneate, striae coarse.

Distribution—Laguna Madre, Aransas, Matagorda and Galveston Bays; Biloxi (Mississippi).

208. *Nitzschia* sp. (Plate 10, Fig. 208).

Valves linear, ends evenly rounded; longitudinal fold close to margin; striae coarsely punctate, transverse; keel puncta not distinct.

Distribution.—Aransas Bay.

Genus *OPEPHORA* Petit, 1888

Frustules rectangular; valves cuneiform, ends unlike; pseudoraphe present; striae transverse, punctate.

209. *Opephora pacifica* (Grunow) Petit (Plate 10, Fig. 209).

Petit (1888, 131), Boyer (1916, 43, 10, 18; 1927, 182), Hustedt (1955, 13, 4, 47–49).

Fragilaria pacifica Grunow (1862, 373, 6, 19).

Valves elongate, pyriform; pseudoraphe lanceolate; striae punctate, coarse, slightly alternate.

Distribution.—Baffin and Aransas Bay; St. Andrews Bay, Florida.

210. *Opephora schwartzii* (Grunow) Petit (Plate 10, Fig. 210).

Petit (1888, 38, 346), Boyer (1916, 43, 10, 16; 1927, 182).

Fragilaria schwartzii Grunow (1863, 143, 5, 7).

Valves linear-ovate, ends rounded; pseudoraphe lanceolate; costae transverse, punctate; fine areolae between costae.

Distribution.—Upper Laguna Madre, Aransas, Galveston Bays; St. Andrews Bay (Florida).

Genus *PINNULARIA* Ehrenberg, 1843

Valves linear with rounded ends; axial area broad, raphe curved; central and terminal areas large; costae smooth, transverse or radiate or a combination of both.

211. *Pinnularia viridis* (Nitzsch) Ehr.

Ehrenberg (1838, 182), A.S.A. (1875, 45, 9–11), Boyer (1927, 446).

Bacillaria viridis Nitzsch (1817, 97).

Valves linear-elliptic with rounded ends; raphe complex; axial area narrow at apices widened towards the middle; costae slightly divergent in the middle, convergent at ends, crossed by a broad band.

v. *rupestris* (Hantzsch) Cleve (Plate 10, Fig. 211).

Cleve (1895, 92).

Striae finer than type.

Distribution.—Matagorda and Galveston Bays.

Genus *PLAGIOGRAMMA* Greville, 1859

Frustules rectangular, in chains or free; valves linear-elliptic to lanceolate with 2 median and 2 terminal costae, and one median and two terminal hyaline spaces.

212. *Plagiogramma obseum* Greville (Plate 10, Fig. 212).

Greville (1865), Boyer (1916, 43, 10, 12).

Valves biconical with rounded ends; central area hyaline, transverse, apical areas rounded; pseudoraphe evident; surface with punctate striae forming radial and longitudinal rows.

Distribution.—Aransas Bay, Matagorda Bay.

213. *Plagiogramma wallichianum* Greville (Plate 10, Fig. 213).

Greville (1865, 13, 1), Boyer (1927, 179), Hustedt (1955, 11, 4, 29).

Valves linear with rounded ends, pseudoraphe narrow or absent; central space rectangular, terminal spaces large; striae at right angles, evident also in central and terminal spaces.

Distribution.—Lower Laguna Madre, Aransas Bay, Matagorda Bay; Pensacola Bay (Florida).

Genus *PLEUROSIGMA* W. Smith, 1852

Valves lanceolate-sigmoid; axial area very narrow; central area small; raphe more or less sigmoid. There seems no valid reason for separating *Pleurosigma* and *Gyrosigma* solely on the striation of the valves, especially as there are much greater differences in valve structure in other genera, e.g., *Mastogloia* and *Navicula* which contain more species, and are not thus divided. The two genera are here considered as one.

214. *Pleurosigma angulatum* (Queckett) W. Smith (Plate 10, Fig. 214, a,b).

W. Smith (1853, 65, 21, 205), Boyer (1916, 74, 22, 61; 1927, 421).

Navicula angulata Queckett (1848, 438, 7, 47).

Valves sigmoid-rhomboid, with at times a definite angle on the valve margin adjacent to the central nodule; raphe sigmoid, central; central nodule small, more or less rhombic; valve surface with fine, oblique cross-hatching, which become transverse-longitudinal at apices. This is not shown in Smith's drawing, or mentioned in his description, but occurs in specimens from the type locality and in the Texas specimens. It does not occur in Australian and New Zealand specimens.

Distribution.—Upper Laguna Madre, Aransas and Matagorda Bays.

215. *Pleurosigma* (*Gyrosigma*) *balticum* (Ehr.) W. Smith (Plate 10, Fig. 215).

W. Smith (1853, 66, 22, 207), Boyer (1916, 75, 23, 2; 1927, 456).

Valves linear with sigmoid extremities; raphe sigmoid and slightly curved close to central nodule; striae longitudinal and transverse.

Distribution.—Laguna Madre, Aransas and Matagorda Bays.

216. *Pleurosigma* (*Gyrosigma*) *beaufortianum* Hustedt (Plate 10, Fig. 216).
Hustedt (1955, 34, 10, 7, 8).

Valves sigmoid, linear-lanceolate with acute ends; raphe central, sigmoid; central nodule extended to a stauros; striae transverse and longitudinal, the latter very fine; the shape varies considerably as shown by Hustedt's and the present illustrations.

Distribution.—Aransas and Galveston Bays.

217. *Pleurosigma* (*Gyrosigma*) *distortum* W. Smith.
W. Smith (1855, 7, 1, 10).

Valves sigmoid, margins evenly rounded, ends acute, sharply rounded; striae transverse and longitudinal.

v. *diaphana* (Cleve) Peragallo (Plate 10, Fig. 217).
Peragallo (1908, 173, 34, 27).

G. diaphana Cleve (1894, 115, 6, 6).

Ends more produced than in type.

Distribution.—Aransas Bay, Galveston Bay.

218. *Pleurosigma distinguendum* Hustedt (Plate 11, Fig. 218 a,b).
Hustedt (1955, 36, 11, 3–5).

Valves lanceolate, with sub-acute, rounded ends slightly produced; raphe sigmoid, ex-centric towards ends with extremities strongly curved in opposite directions; axial and central areas narrow; striae oblique, equidistant; these specimens have a more sigmoid raphe with less undulation than those figured by Hustedt.

Distribution.—Galveston Bay.

219. *Pleurosigma* (*Gyrosigma*) *fasciola* (Ehrenberg) W. Smith (Plate 11, Fig. 219).
W. Smith (1853, 67, 21, 211), Boyer (1927, 463).

Valves sigmoid, extremities drawn out into long, curving beaks, raphe almost straight, central to beaks, then sigmoid; striae transverse and longitudinal.

Distribution.—Upper and Lower Laguna Madre, Aransas and Matagorda Bays.

220. *Pleurosigma formosum* W. Smith (Plate 11, Fig. 220).
W. Smith (1853, 63, 20, 195), Boyer (1916, 73, 22, 5; 1927, 467).

Valves sigmoid; raphe strongly sigmoid, sweeping from central nodule towards valve margin, giving a very twisted appearance; striae oblique forming a diamond-shaped network.

Distribution.—Laguna Madre, Baffin, Aransas, Matagorda and Galveston Bays.

221. *Pleurisigma naviculaceum* Breb. (Plate 11, Fig. 221).
Brebisson (1867, 17), Boyer (1916, 74, 22, 6; 1927, 471).

Valves lanceolate, slightly sigmoid at the subacute ends; raphe nearly central, sigmoid near ends; central nodule dilated transversely; striae oblique in 2 directions.

Distribution.—Aransas and Matagorda Bays.

222. *Pleurosigma* (*Gyrosigma*) *peisonis* Grunow (Plate 11, Fig. 222 a,b).
Grunow (1860, 562, 6, 8), Hustedt (1955, 10, 4).

Valves with parallel sides, inner and outer margins both sigmoid; raphe sinuate,

median, then approaching outer margin; striae coarse, transverse and longitudinal. Distribution.—Matagorda Bay; Pascagoula (Mississippi).

223. *Pleurosigma (Gyrosigma) simile* Grunow (Plate 11, Fig. 223).
Grunow (1860, 56), Boyer (1916, 76, 23, 4; 1927, 457).

Valves linear, one margin sharply rounded giving a bluntly sigmoid appearance to the valve; raphe sigmoid at ends; striae transverse and longitudinal.

Distribution.—Aransas and Matagorda Bays.

Genus *PODOSIRA* Ehrenberg, 1840

Frustules spheroidal to lenticular; single or in pairs; valve surface with fasciculate areolae.

224. *Podosira hormoides* (Mont.) Kützing (Plate 11, Fig. 224 a,b).
Kützing (1844, 52, 28, 5, 29, 84), Hustedt (1928, 283, 123).
Trochiscia moniliformis Montagne (1837, 349).
Melosira hormoides Montagne (1839, 2).

Frustules lenticular with strongly convex valves; without valve mantle; valve surface with fasciculate rays of areolae.

Distribution.—Aransas and Matagorda Bays.

Genus *PYXIDICULA* Ehrenberg, 1833

Frustules globular, solitary or in pairs; valves more or less hemispherical, areolate, without spines.

225. *Pyxidicula cruciata* Ehrenberg (Plate 11, Fig. 225).
Ehrenberg (1833, 3, 8), Boyer (1916, 19, 38, 8).

Cells solitary or in pairs; valves hemispherical with large, hexagonal areolae, largest at center, uniform towards valve margins; no constriction between valve and girdle; no spines, spinules or processes.

Distribution.—Baffin, Aransas and Matagorda Bays.

Genus *RHABDONEMA* Kützing, 1844

Frustules rectangular, in chains or single; containing a number of septa; surface costate, costae united by cross ribs.

226. *Rhabdonema adriaticum* Kützing (Plate 11, Fig. 226).
Kützing (1844, 126, 18, 7), Boyer (1927, 150).

Cells in ribbons, shortly stipitate; frustules in girdle view square to oblong with rounded corners, multiseptate, septa with 3 foramina in valve view; valves linear with rounded ends; surface in girdle view costate, costae united by cross ribs, in valve view transversely striate, striae with hyaline areas at each end.

Distribution.—Aransas Bay.

Genus *RHAPHONEIS* Ehrenberg, 1844

Frustules linear in girdle view, lanceolate, to elliptic, lanceolate in valve view; pseudo-
raphe distinct.

227. *Rhaphoneis ampiceros* Ehr. (Plate 11, Fig. 227 a).

Ehrenberg (1884, 87), A.S.A. (1911, 269, 44–45), Boyer (1927, 190).

Valves broadly lanceolate to semicircular, with produced ends; striae moniliform, radiating, granulate, the granules in longitudinal lines.

Distribution.—Laguna Madre, Aransas Bay.

228. *Rhaphoneis castracanei* Grunow (Plate 11, Fig. 228).

Grunow (in van Heurck, 1880–85, 36, 28), A.S.A. (294, 35–37).

Valves hexagonal, with concave sides; pseudoraphe linear-lanceolate; puncta coarse forming curved striae.

Distribution.—Aransas Bay.

229. *Rhaphoneis surirella* (Ehrenberg) Grunow (Plate 11, Fig. 229 a).

Grunow in van Heurck (1880–85, 36, 26, 27a).

Zygoceros surirella Ehrenberg (1840, 4, 12).

Valves elliptical, ends slightly acute; pseudoraphe narrow, slightly wider at ends; puncta irregularly spaced in middle.

Distribution.—Lower Laguna Madre.

v. *australis* Petit (Plate 11, Fig. 229 b,c).

Petit (1877, 174, 4–6).

Dimerogramma australe Boyer (1927).

Valves elliptical to linear elliptic, ends acute; pseudoraphe broad, slightly constricted in the middle; striae coarse, punctate, radiate at ends, transverse in the middle, forming longitudinal rows.

Distribution.—Aransas Bay.

Genus *RHOPALODIA* Müller, 1885

Frustules in girdle view linear to clavate; valves reniform to lunate; raphe on convex edge, often not visible; the separation of this genus from *Epithemia* is questionable.

230. *Rhopalodia gibberula* (Ehrenberg) O. Müller (Plate 12, Fig. 230 a-d).

Boyer (1927, 450).

Eunotia gibberula Ehrenberg (1843, 125).

Frustule elliptic-lanceolate; valves lunate, ends may be rostrate, very variable; costae distant with intermediate rows of fine puncta.

Distribution.—Upper and Lower Laguna Madre, Baffn, Aransas, Corpus Christi, Matagorda and Galveston Bays (rare in upper waters of the last two).

231. *Rhopalodia musculus* (Kützing) O. Müller (Plate 11, Fig. 231 a).

O. Müller (1895, 278), A.S.A. (1905, 255, 1–12).

Epithemia musculus Kützing (1844, 33, 30, 6).

Boyer (1927, 490).

Frustules elliptical with acute, slightly truncate ends; costae well marked, alternating with rows of fine punctae striae.

Distribution.—Aransas Bay.

v. *constricta* Breb. (Plate 11, Fig. 231 b, 12, 231 c).

Brebisson in W. Smith (1853).

Valves slightly constricted in the middle.

Distribution.—Laguna Madre, Baffin, Aransas, rare in Matagorda and Galveston Bays.

Genus *SKELETONEMA* Greville, 1865

Frustules discoid, forming chains united by a series of marginal filaments which may be as long as cells and are joined by nodes.

232. *Skeletonema costatum* (Greville) Cleve (Plate 12, Fig. 232).

Cleve (1878, 18).

Melosira costata Greville (1866, 8, 3–6).

Chains thin, usually straight; cells lenticular to cylindrical, joined by a row of straight, interlocking marginal spines. Spores brown, spherical bodies.

Distribution.—Galveston Bay (common in sediments of this area).

Genus *STAURONEIS* Ehrenberg, 1843

Valves lanceolate; raphe straight; axial area straight, central area forming a stauros.

233. *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg (Plate 12, Fig. 233).

Ehrenberg (1843, 134), Boyer (1927, 421), Hustedt (1937, 766, 1118).

Bacillaria phoenicenteron Nitzsch (1817, 92, 4).

Valves lanceolate with obtuse ends, may be slightly produced; axial area linear, stauros transverse; puncta in longitudinal and oblique rows.

Distribution.—Lower Laguna Madre, Aransas Bay; Pensacola Bay, (Florida).

Genus *STENOPTEROBIA* Brebisson, 1837

Valves linear to sigmoid with blunt ends; costae marginal, central area finely striate.

234. *Stenopteroibia intermedia* (Lewis) Hustedt (Plate 12, Fig. 234).

Hustedt in A.S.A. (1912, 284).

Surirella intermedia Lewis (1863, 338).

Nitzschia sigmatella Gregory (1858, 38, 4, 2).

Frustules linear in girdle view or may be slightly sigmoid; in valve view linear, sigmoid at the ends, tapering to subacute; costae inconspicuous, reaching the narrow central space; striae indistinct.

Distribution.—Laguna Madre, Aransas and Galveston Bays.

Genus *STEPHANODISCUS* Ehrenberg, 1845

Frustules discoid, single; valves usually concentrically swollen with a marginal ring of spinulae; striae radial, coarse in marginal zone, fine in central area.

235. *Stephanodiscus dubius* (Fricke) Hustedt (Plate 12, Fig. 235).

Hustedt (1927, 367, 192).

Cyclotella dubia Fricke, in A.S.A. (1900, 222, 23).

Frustules discoid, valves concentrically undulate; radially punctate, striate, forming marginal ribs in a narrow marginal zone; middle radially punctate; marginal spines short, barely visible in valve view.

Distribution.—Aransas and Galveston Bays.

Genus *SURIPELLA* Turpin, 1828

Valves linear, elliptic to ovate; central area linear to lanceolate; raphe borne on marginal wings; costae short or reaching central area.

236. *Surirella biseriata* Breb. (Plate 12, Fig. 236).

Brebisson (1838, 53, 7), A.S.A. (283, 2), Boyer (1916, 124, 35, 2; 39, 12; 1927, 535).

Valves lanceolate, subcuneate at ends; costae strong, parallel in the middle, radiate at the ends; central area linear.

Distribution.—Pascagoula (Mississippi).

237. *Surirella fastuosa* (Ehrenberg) Kützing (Plate 12, Fig. 237).

Kützing (1844, 62, 28, 19), Boyer (1916, 127, 35, 1; 1927, 544).

Navicula fastuosa Ehrenberg (1841, 19).

Frustules in valve view ovate to broadly elliptic; valves with costae inflated at margins, tapering to a central area which is broadly lanceolate and hyaline or faintly striate, striae more evident at margins and towards the center where they are well defined.

Distribution.—Aransas Bay, Lower Laguna Madre; Pensacola Bay (Florida).

238. *Surirella fluminensis* Grunow (Plate 12, Fig. 238).

Grunow (1862, 463), A.S.A. (1875, 5, 6), Peragallo (1908, 249, 60, 1, 2).

Valves ovate; costae strong at margin, tapering to linear central area; punctate striae between the costae.

Distribution.—Matagorda Bay; Lake Pontchartrain (Louisiana).

239. *Surirella ovata* Kützing (Plate 12, Fig. 239).

Kützing (1844, 62, 7, 1–4), A.S.A. (23, 49–55), Boyer (1927, 541).

Valves ovate; costae marginal, central area large, ovate, finely striate.

Distribution.—Galveston Bay.

240. *Surirella patella* Kützing (Plate 12, Fig. 240).

Kützing (1844, 61, 7, 5), Cleve-Euler (1952, 120, 1561f).

Valves ovate to linear-ovate; costae marginal, central area finely striate; central line present; form very variable.

Distribution.—Upper Laguna Madre.

241. *Surirella recedens* A.S. (Plate 12, Fig. 241).

A.S.A. (19, 2, 3, 4; 24, 28), Boyer (1916, 127, 35, 7).

Valves elliptic to ovate; central area striate, with hyaline middle; costae coarse, tapering to central area, lower costae joining below central area.

Distribution.—Lower Laguna Madre.

242. *Surirella regina* Janisch (Plate 12, Fig. 242).

Janisch (in A.S.A., 24, 5).

Valves elliptic to ovate; costae fine, reaching linear central area; with punctate striae in between.

Distribution.—Galveston Bay.

243. *Surirella striatula* Turpin (Plate 12, Fig. 243).

Turpin (1828, 508), A.S.A. (24, 18–22), Boyer (1916, 125, 34, 1).

Valves broad, ovate to elliptic; costae fine, curved at ends; central area linear.

Distribution.—Pensacola (Florida).

Genus *SYNEDRA* Ehrenberg, 1830

Frustules attached or free; valves elongate-linear to linear-lanceolate; pseudoraphe distinct; striate.

244. *Synedra acus* Kützing (Plate 12, Fig. 244).

Kützing (1844, 68), A.S.A. (1914, 303, 7), Boyer (1916, 18, 11, 9; 1927, 201).

Frustules elongate, slender; valves linear-lanceolate, acicular, ends elongate, subcapitate or obtuse; striae transverse; pseudoraphe usually evident.

Distribution.—Upper Laguna Madre; Corpus Christi, Aransas and Matagorda Bays; Pascagoula (Mississippi).

245. *Synedra formosa* Hantzsch (Plate 12, Fig. 245 a,b).

Hantzsch (in Rabenhorst, 1863, 19, 5, 3), Hustedt (1931, 234, 720).

Valves linear, often slightly narrowed in the middle; and constricted towards the rounded ends; transapical ribs coarse; cell wall chambered with small, circular pores.

Distribution.—Lower Laguna Madre; Aransas and Matagorda Bays.

246. *Synedra hennedyana* Gregory

Gregory (1857, 21, 532), Boyer (1927, 211).

Frustules elongate, acicular; valves elongate, swollen in the middle, apices capitate; pseudoraphe indistinct; striae transverse, irregular in the middle; no satisfactory illustration could be provided of this very elongate species.

Distribution.—Aransas Bay.

247. *Synedra ulna* (Nitzsch) Ehrenberg (Plate 12, Fig. 246 a,b).

Ehrenberg (1838, 211), Boyer (1927, 198).

Bacillaria ulna Nitzsch (1817, 99).

Cells colonial or single; frustules in valves view linear, suddenly constricted towards

extremities or not; pseudoraphe distinct; striae transverse; median area quadrangular. Distribution.—Laguna Madre, Aransas, Copano, San Antonio, and Galveston Bays.

Genus *TRACHYSPHENIA* Petit, 1877

Frustules rectangular; valve more or less cunieforn with coarse puncta in transverse and longitudinal lines; pseudoraphe narrow, linear.

248. *Trachysphenia acuminata* Peragallo (Plate 12, Fig. 247).
Peragallo (1911, 11, 2, 10), Hustedt (1955, 14, 4, 50–54).

Valves lanceolate, strongly rostrate, rarely heteropolar; striae transverse, punctate; pseudoraphe narrow.

Distribution.—Upper Laguna Madre, Aransas and Matagorda Bays; St. Andrews Bay (Florida).

Genus *TERPSINOE* Ehrenberg, 1841

Frustules rectangular; valves penetrated by numerous septa; in valve view lobed.

249. *Terpsinoe americana* (Bailey) Ralfs (Plate 12, Fig. 248 a,b).
Ralfs (in Pritchard, 1861, 859), Boyer (1927, 145).
Tetragramma americana Bailey (1853).

Frustules quadrangular, with septa extending about half way into valve; valves with undulating margin, inflated in the middle, ends rostrate; divided into 3–4 segments by the septa; surface with coarse but indistinct puncta.

Distribution.—Matagorda Bay; Pensacola (Florida).

Genus *TRACHYNEIS* Cleve, 1894

Valves linear-lanceolate; valve surface threefold, with coarse, dotted, irregularly alveolate and finely punctate layers; central area cruciform, often asymmetric.

250. *Trachyneis aspera* (Ehr.) Cleve (Plate 12, Fig. 249).
Cleve (1894, 191).
Pinnularia aspera Ehrenberg (1840, 213).
Navicula aspera Ehr. (1854, 35).

Frustules rectangular in girdle view with rounded corners and a median constriction; girdle broad, finely punctate; valves elliptic-lanceolate to rhomboid with obtuse ends; axial area narrow, unilateral; central area transversely dilated, widened outward; alveoli radiate in oblique rows.

Distribution.—Lower Laguna Madre, Aransas and Matagorda Bays.

Genus *TRICERATIUM* Ehrenberg, 1849

Frustules rectangular with processes at or near valve angles, and often with spines; valves triangular to polygonal, surface areolate or striate. Boyer unites *Triceratium* with *Biddulphia*.

251. *Triceratium reticulum* Ehr. (Plate 12, Fig. 250).

Ehrenberg (1844, 88, 18, 50, 33, 16, 33).

Biddulphia reticulum Boyer (1901).

Valves triangular to polygonal with straight or concave sides; angles rounded, sometimes produced; surface slightly elevated at center and angles; puncta angular, unequal, larger at center; three or four spines may occur about half way between center and margins; groups of puncta frequently occur arranged in 3 or 4 circles.

Distribution.—Aransas Bay.

Genus *TROPIDONEIS* Cleve, 1891

Frustules rectangular, constricted in the middle, winged keel not sigmoid; axial area not evident.

252. *Tropidoneis lepidoptera* (Gregory) Cleve (Plate 12, Fig. 251 a,b).

Cleve (1894, 25), Boyer (1916, 69, 14, 8, 9).

Amphiprora lepidoptera Gregory (1857, 505, 4, 59).

Frustules in valve view ovate-lanceolate, in girdle view strongly depressed centrally forming a figure 8; lateral areas more or less hyaline; striae transverse, reaching the lateral longitudinal line.

Distribution.—Laguna Madre, Aransas Bay.

Some Characteristics of the Diatom Flora

The relations between the numbers of photosynthetic micro-organisms of the surface sediments of the South Texas bays and their environment will be the subject of a separate paper. However, it is possible to characterize the various bays by their diatom flora.

The Lower Laguna Madre below the Land Cut is noteworthy for the relative abundance in numbers and species of the genus *Cocconeis* which tends to dominate; *Rhopalodia* is also abundant and *Grammatophora* frequent.

In the Upper Laguna Madre, *Cocconeis* is less important, while *Amphora* is frequently dominant, *Rhopalodia* abundant and *Achnanthes*, *Actinopterychus*, *Grammatophora* frequent.

Baffin Bay has few diatoms, and few species, but the lower part resembles the Upper Laguna Madre into which it opens.

Corpus Christi Bay (including Redfish Bay) and Aransas Bay have a great deal in common as would be expected with the continuous movement of shipping into both these bays through Aransas Pass, and the consequent stirring up of the bottom. *Rhopalodia* and *Amphora* dominate, *Mastogloia* is abundant as a rule, especially in Aransas Bay and Redfish Bay, while *Achnanthes*, *Actinopterychus*, *Cocconeis*, *Coscinodiscus*, *Diploneis* and *Grammatophora* are noteworthy.

In San Antonio and Espiritu Santo Bays, *Coscinodiscus* and *Cyclotella* are the most important diatom genera, though the numbers are relatively low.

Matagorda Bay contains *Actinopterychus*, *Achnanthes*, *Diploneis* and *Cyclotella*.

Galveston Bay has *Diploneis*, *Coscinodiscus* and *Cyclotella*.

The presence of *Rhopalodia*, a genus often associated with fresh to slightly brackish water, in the Laguna Madre and east to Aransas Bay is significant, as is the abundance and frequent dominance of *Amphora* in the Upper Laguna Madre, Redfish and Aransas Bays. Samples from the latter two taken through the three-month period of my stay were consistent in the persistence and relative importance of these two genera.

Cyclotella is more frequent in the eastern bays, especially Matagorda and Galveston Bays.

Nitzschia and *Navicula* were widely distributed through the area but only a few species were characteristic, e.g. *Navicula yarrensis* in Redfish Bay and western Aransas Bay, while some, e.g. *Nitzschia granulata* were cosmopolitan.

It is always difficult to convey the criteria by which an experienced observer can characterize the flora of a region and parts thereof, and the above comments can only be regarded as a summary of these criteria. Much depends on the relative numbers of the dominant, sub-dominant and even the rarer species, the species assemblages and even the form of such variable species as *Nitzschia sigma*, *N. obtusa* and *Cyclotellas*.

Plate 1.

Fig. 1 a,b. *Achnanthes biasolettiana*; Fig. 2. *A. brevipes*; Fig. 3 a,b. *A. curvirostrum*; Fig. 4 a,b. *A. delicatula*; Fig. 5 a,b. *A. exilis*; Fig. 6. *A. hauckiana*; Fig. 7. *A. hungarica*; Fig. 8. *A. lemmermannii*; Fig. 9. *A. longipes*; Fig. 10. a,b. *A. manifera*; Fig. 11. a,b. *A. tenera*; Fig. 12. *Actinocyclus octodenarius*; 12 a, v. *ralfsii*; 12 b, v. *sparsa*; 12 c, v. *tenella*; Fig. 13. *Actinoptychus campanulifer*; Fig. 14. *A. senarius*; Fig. 15. *A. taenatus*; Fig. 16 a,b. *Amphiprora alata*; Fig. 17. *A. gigantea*.

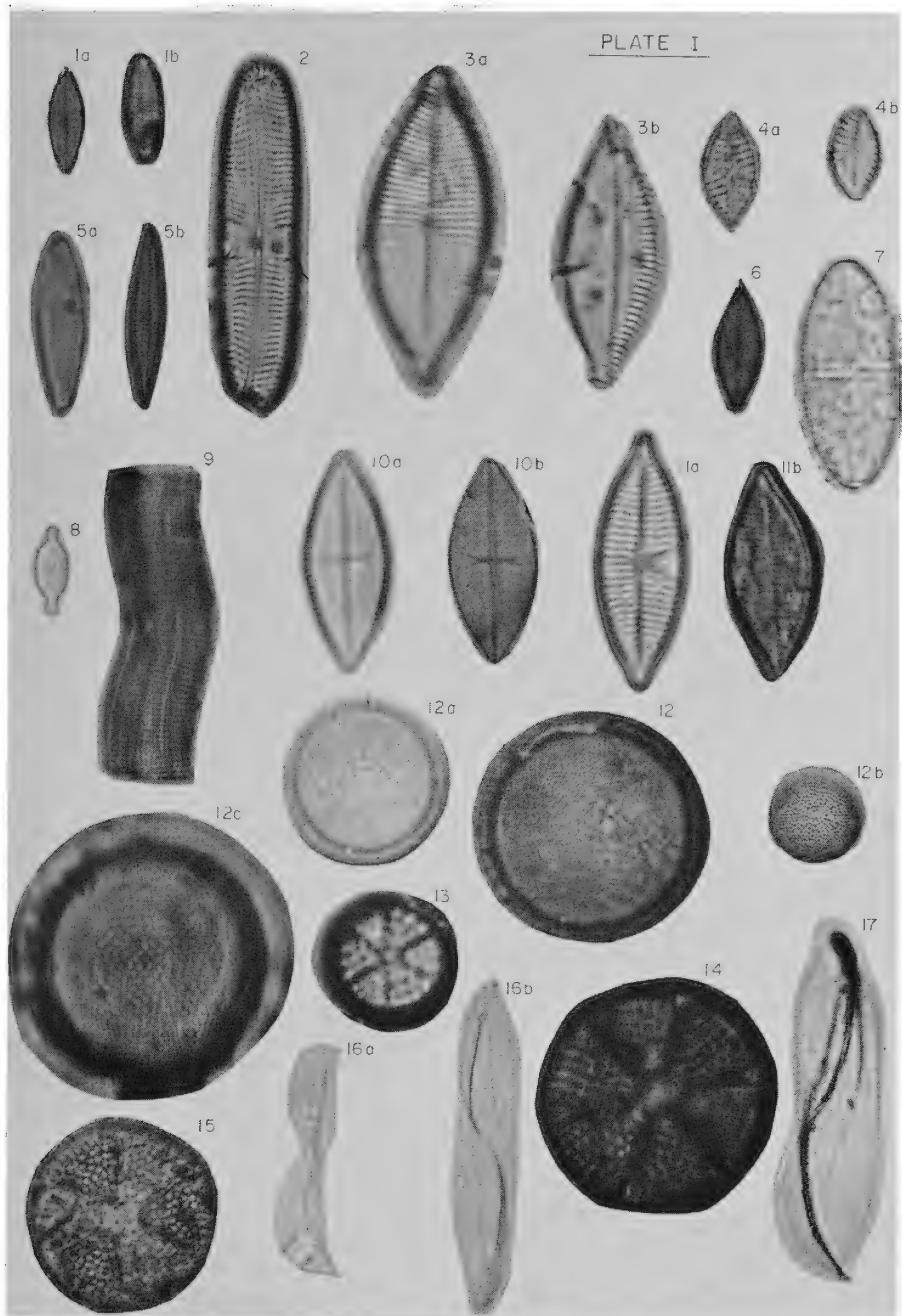


Plate 2.

Fig. 18. *Amphora acuta* v. *arcuata*; Fig. 19. *A. angularis*; Fig. 20. *A. angusta*; Fig. 21. *A. arenaria*; Fig. 22. *A. aspera*; Fig. 23. *A. capensis*; Fig. 24. *A. coffaeiformis*; Fig. 25. *A. decussata*; Fig. 26. *A. delphineae*; Fig. 27 a,b. *A. dubia*; Fig. 28 a,b. *A. egregia*; Fig. 29. *A. graeffii*; Fig. 30. *A. granulata*; Fig. 31. *A. hyalina*; Fig. 32 a,b. *A. javanica*; Fig. 33. *A. laevis*; Fig. 34. *A. mexicana*; Fig. 35 a,b. *A. obtusa*; Fig. 36 a-c. *A. proteus*.

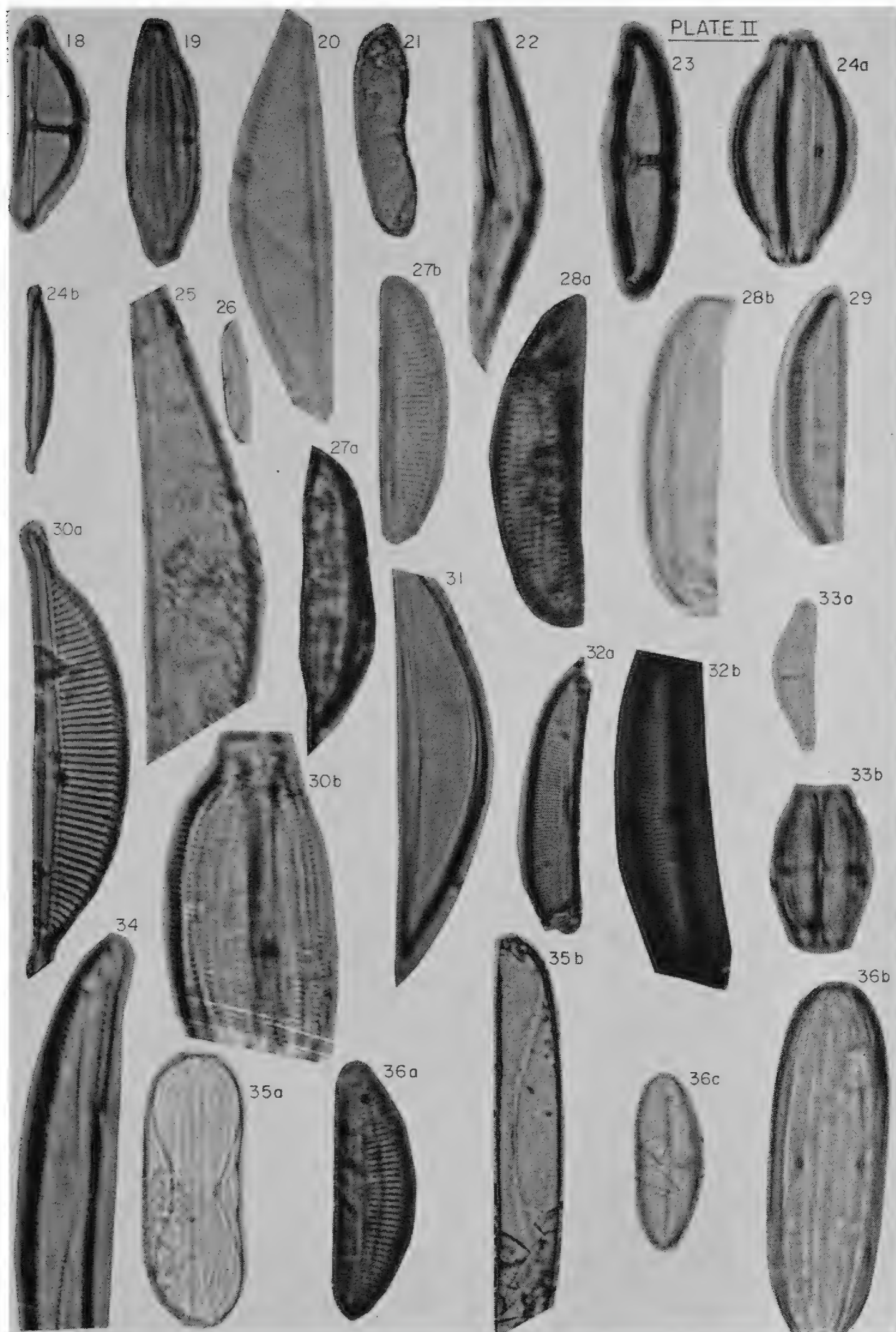


Plate 3.

Fig. 37. *A. robusta*; Fig. 38. *A. spectabilis*; Fig. 39. *A. turgida*; Fig. 40 a,b. *A. terroris*; Fig. 41. *A. weissflogii*; Fig. 42. *Amphora* sp. 1; Fig. 43. *A.* sp. 2; Fig. 44. *Asteromphalus flabellatus*; Fig. 45. *Auliscus reticulatus*; Fig. 46. *Bacillaria paxillifer*; Fig. 47. *Bacteriastrum varians*; Fig. 48. *Biddulphia aurita*; Fig. 49. *B. laevis*; Fig. 50. *B. longicruris*; Fig. 51. *B. mobiliensis*; Fig. 52. *B. pulchella*; Fig. 53. *B. subaequa*; Fig. 54. *B.* sp.; Fig. 55. *Caloneis formosa*; Fig. 56. *C. latiuscula*.

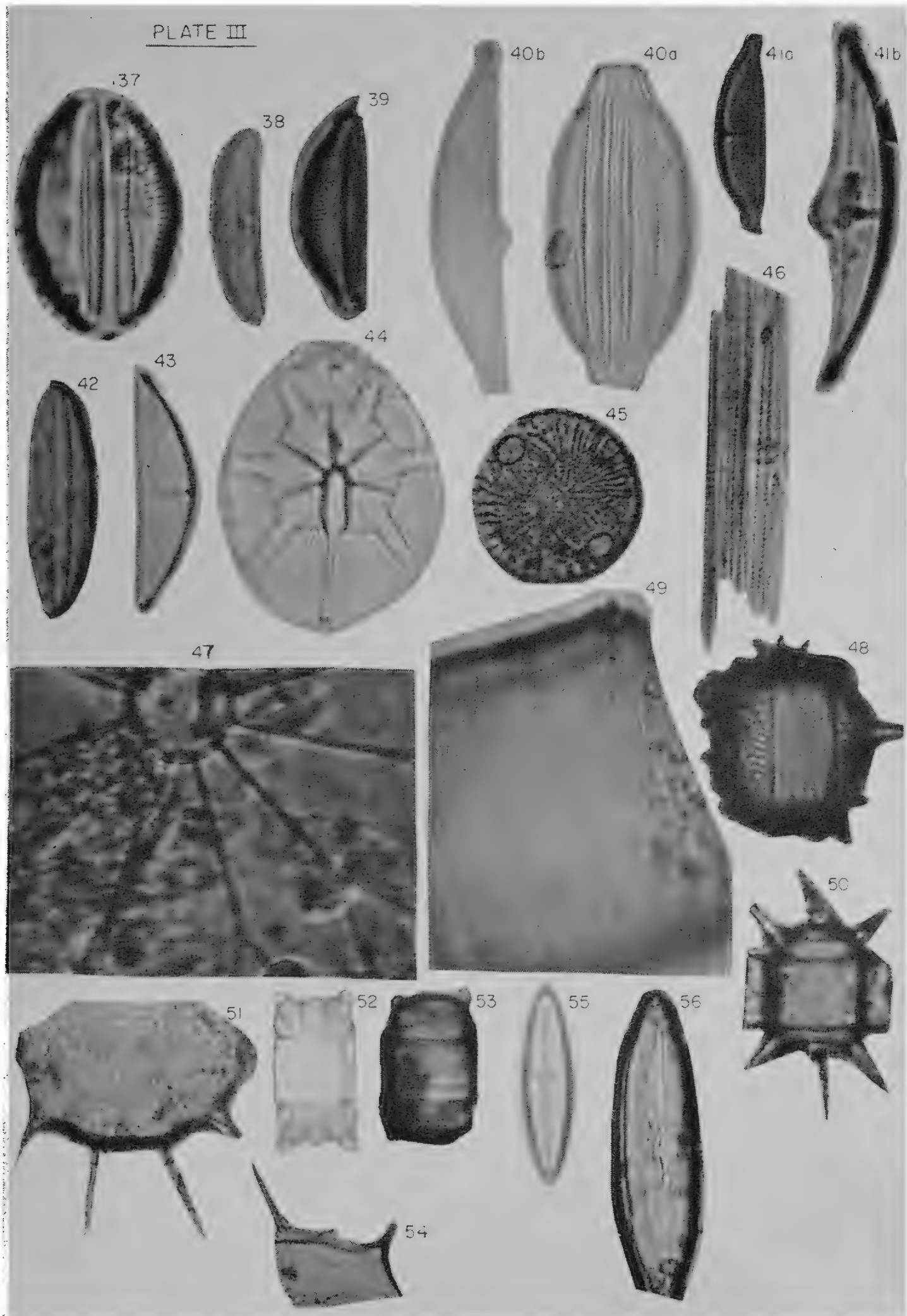


Plate 4.

Fig. 57. *Caloneis liber*; Fig. 58. *C. permagna*; Fig. 59. *C. probabilis*; Fig. 60. *Campylodiscus biangulatus*; Fig. 61. *C. echeneis*; Fig. 62. *C. hibernicus*; Fig. 63. *Campylosira cymbelliiformis*; Fig. 64. *Cocconeis apiculata*; Fig. 65. *C. costata*; Fig. 66 a,b. *C. disculoides*; Fig. 67. *C. disculus*; Fig. 68. *C. distans*; Fig. 69. *C. heteroidea*; Fig. 70. *C. maxima*; Fig. 71 a,b. *C. pensacolae*; Fig. 72. *C. placentula*; Fig. 73a. *C. scutellum*; Fig. 73 b. v. *stauroneiformis*; Fig. 74. *C. sp.*

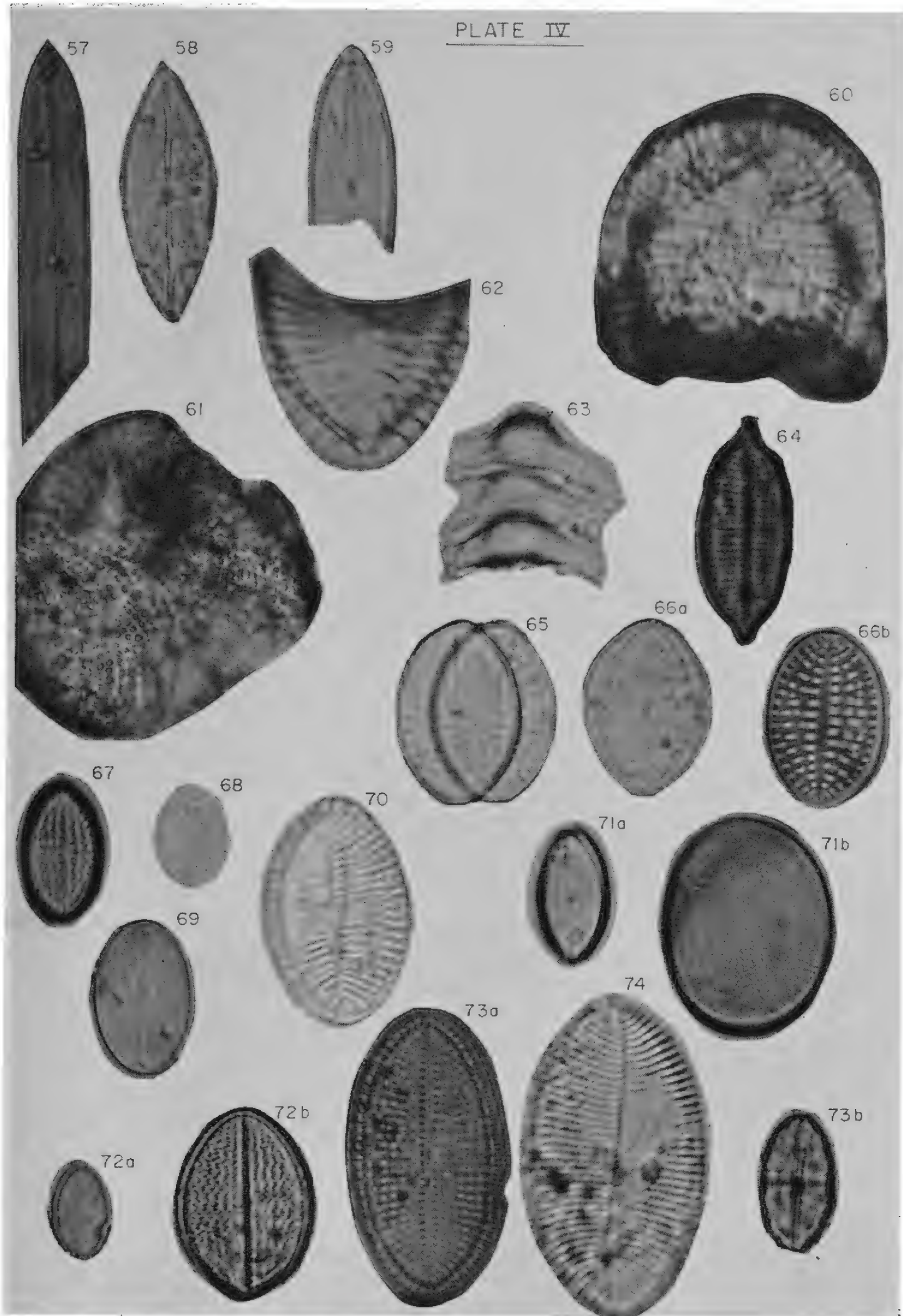


Plate 5.

Fig. 75. *Coscinodiscus argus*; Fig. 76. *C. asteromphalus*; Fig. 77. *C. blandus*; Fig. 78. *C. concavus*; Fig. 79. *C. decrescens*; Fig. 80. *C. divisus*; Fig. 81. *C. elegans*; Fig. 82. *C. excentricus*; Fig. 83. *C. kuetzingii*; Fig. 84. *C. lineatus*; Fig. 85. *C. moelleri*; Fig. 86. *C. marginatus*; Fig. 87. *C. nodulifer*; Fig. 88. *C. oculus iridis*; Fig. 89. *C. radiatus*; Fig. 90. *C. rothii*; Fig. 91. *C. sp. 1*; Fig. 92. *C. sp. 2*.

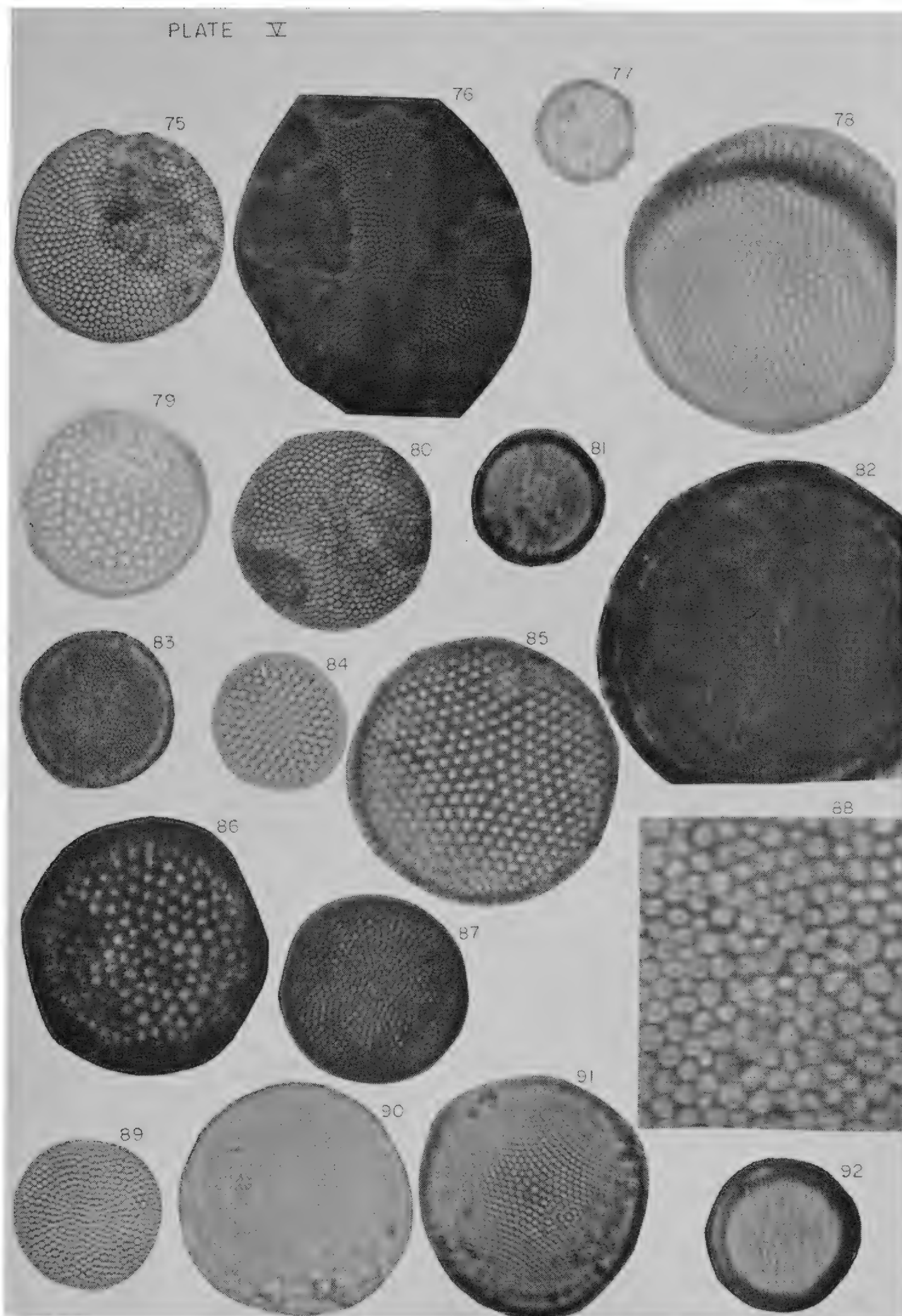


Plate 6.

Fig. 93. *Coccosira mediterranea*; Fig. 94. *Cosmiodiscus elegans*; Fig. 95. *Cyclotella comta*; Fig. 96. *C. kuetzingiana*; Fig. 97. *C. meneghiniana*; Fig. 98. *C. striata*; Fig. 99. *C. stylorum*; Fig. 100 a. *Cymbella cistula*; Fig. 100 b. *C. cistula* v. *maculata*; Fig. 101. *C. yarrensii*; Fig. 102. *Diatoma hiemale*; Fig. 103 a,b. *Dimerogramma marinum*; Fig. 104 a-d. *D. minor*; Fig. 105. *Diploneis bombus*; Fig. 106. *D. chersonensis*; Fig. 107. *D. cynthia*; Fig. 108. *D. fusca*; Fig. 109. *D. gemmatula*; Fig. 110. *D. ovalis*; Fig. 111. *D. papula*; Fig. 112. *D. smithii*; Fig. 113. *D. splendida*; Fig. 114. *D. weissflogii*; Fig. 115. *Endictya oceanica*; Fig. 116. *Epithemia argus*; Fig. 117. *E. zebra*; Fig. 118. *Eunotia hebridica*.

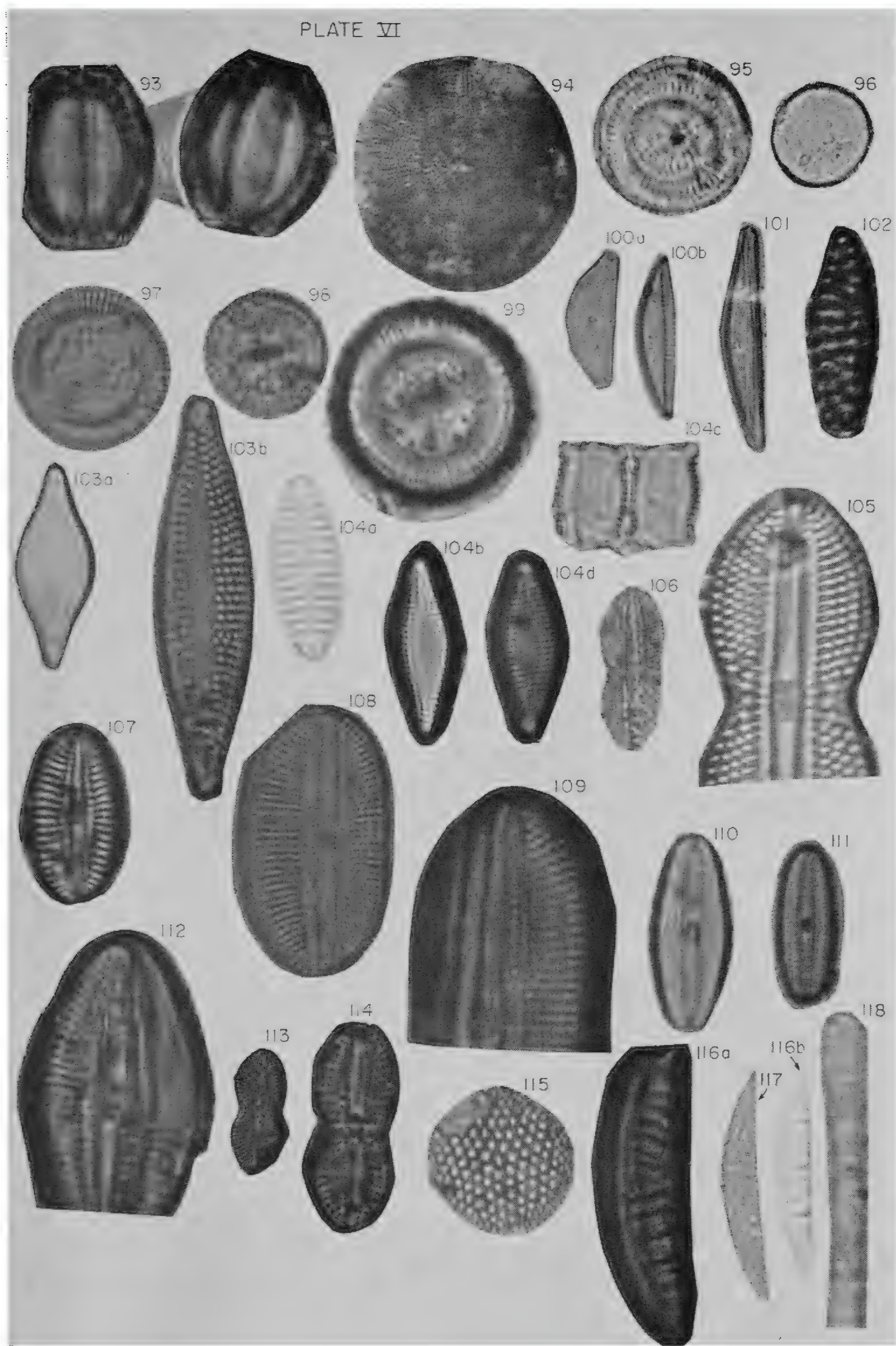


Plate 7.

Fig. 119. *Eunotogramma laeve*; Fig. 120. *E. marinum*; Fig. 121. *Eupodiscus ovalis*; Fig. 112. *E. radiatus*; Fig. 123. *Fragilaria brevistriata*; Fig. 124. *F. capucina*; Fig. 125. *F. construens*; Fig. 126. *F. pinnata*; Fig. 127. *F. virescens*; Fig. 128 a,b. *Frustulia interposita*; Fig. 129 a. *F. rhomboides*; 129 b. *F. rhomboides* v. *saxonica*; Fig. 130. *Grammatophora maxima*; Fig. 131 a,b. *G. marina*; Fig. 132. *G. oceanica*; Fig. 133. *Hantzschia amphioxys* v. *compacta*; Fig. 134. *H. marina*; Fig. 135. *Huttonia reichardtii*; Fig. 136. *Licmophora flabellata*; Fig. 137. *Lithodesmium undulatum*; Fig. 138 a,b. *Mastogloia acutiuscula*; Fig. 139. *M. angulata*; Fig. 140 a,b. *M. apiculata*; Fig. 141. *M. asperula?*; Fig. 142. *M. baldjikiana*; Fig. 143. *M. binotata*.

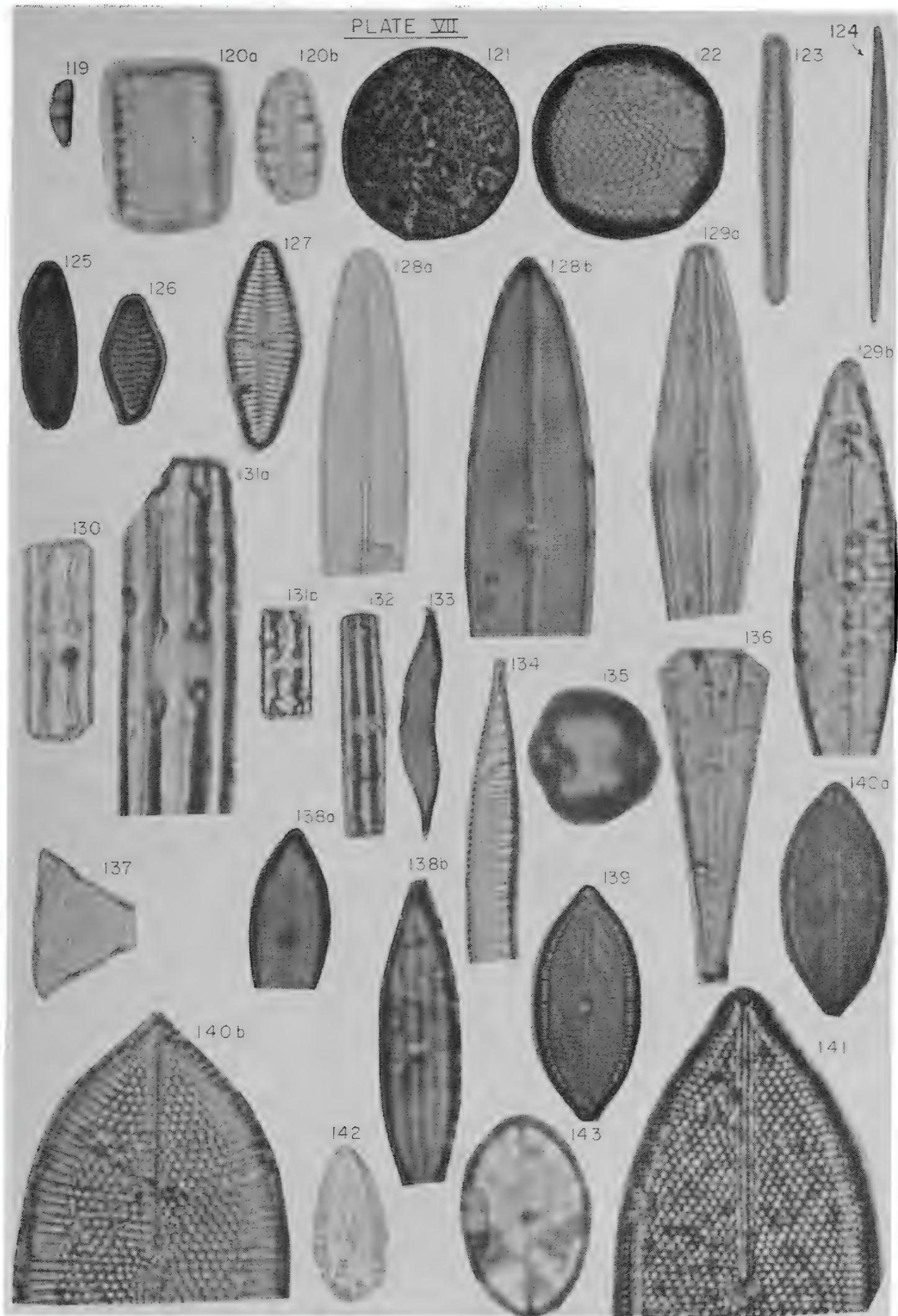


Plate 8.

Fig. 144. *Mastogloia braunii*; Fig. 145. *M. chersonensis*; Fig. 146. *M. cocconeiformis*; Fig. 148 a,b. *M. crucicula*; Fig. 149. *M. erythraea*; Fig. 150. *M. horvathiana*; Fig. 151. *M. labuensis*; Fig. 152 a,b. *M. lanceolata*; Fig. 153. *M. latericia*; Fig. 154 a-c. *M. pumila*; Fig. 155. *M. pusilla*; Fig. 156. *M. quinquecostata*; Fig. 157. *M. smithii*; Fig. 158 a,b. *M. subaffirmata*; Fig. 159. *Melosira granulata*; Fig. 160. *M. nummuloides*; Fig. 161. *M. ornata*; Fig. 162. *M. setosa*; Fig. 163. *M. sulcata*; Fig. 164. *Navicula ambigua*.

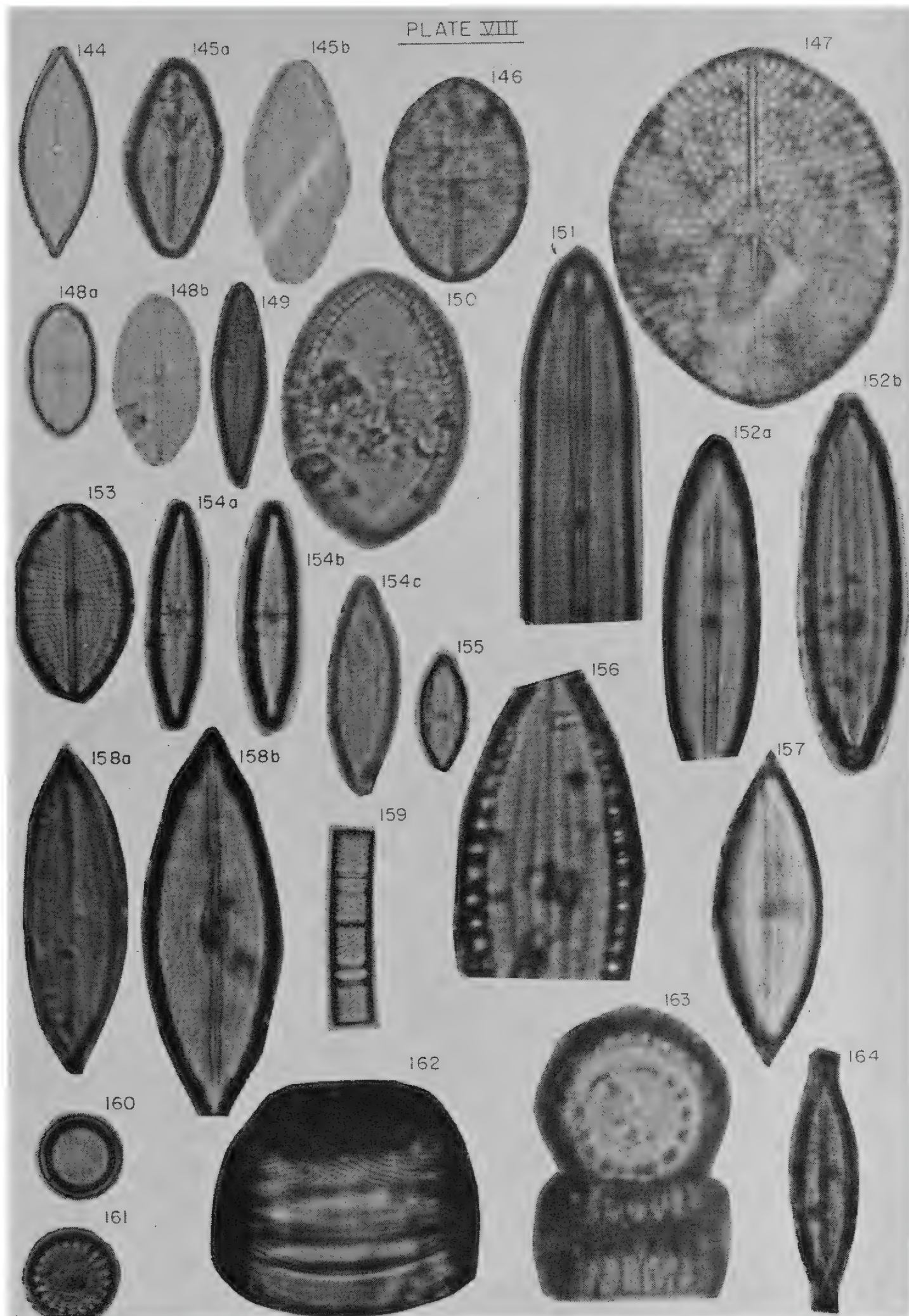


Plate 9.

Fig. 165. *Navicula clavata*; Fig. 166. *N. delawarensis*; Fig. 167. *N. directa*; Fig. 168. *N. distans*; Fig. 169. *N. diversistriata*; Fig. 170. *N. forcipata*; Fig. 171. *N. granulata*; Fig. 172. *N. grevillei*; Fig. 173. *N. hummii*; Fig. 174. *N. impressa*; Fig. 175. *N. longa*; Fig. 176. *N. nummularia*; Fig. 177. *N. peregrina*; Fig. 178. *N. pseudobacillum*; Fig. 179. *N. punctigera*; Fig. 180. *N. rostellata*; Fig. 181. *N. ruttneri*; Fig. 182. *N. seductilis*; Fig. 183. *N. spuria*; Fig. 184. *N. subcarinata*; Fig. 185. *N. subdiffusa*; Fig. 186. *N. viridula*; Fig. 187. *N. weissflogii*; Fig. 188. *N. yarrensis*.

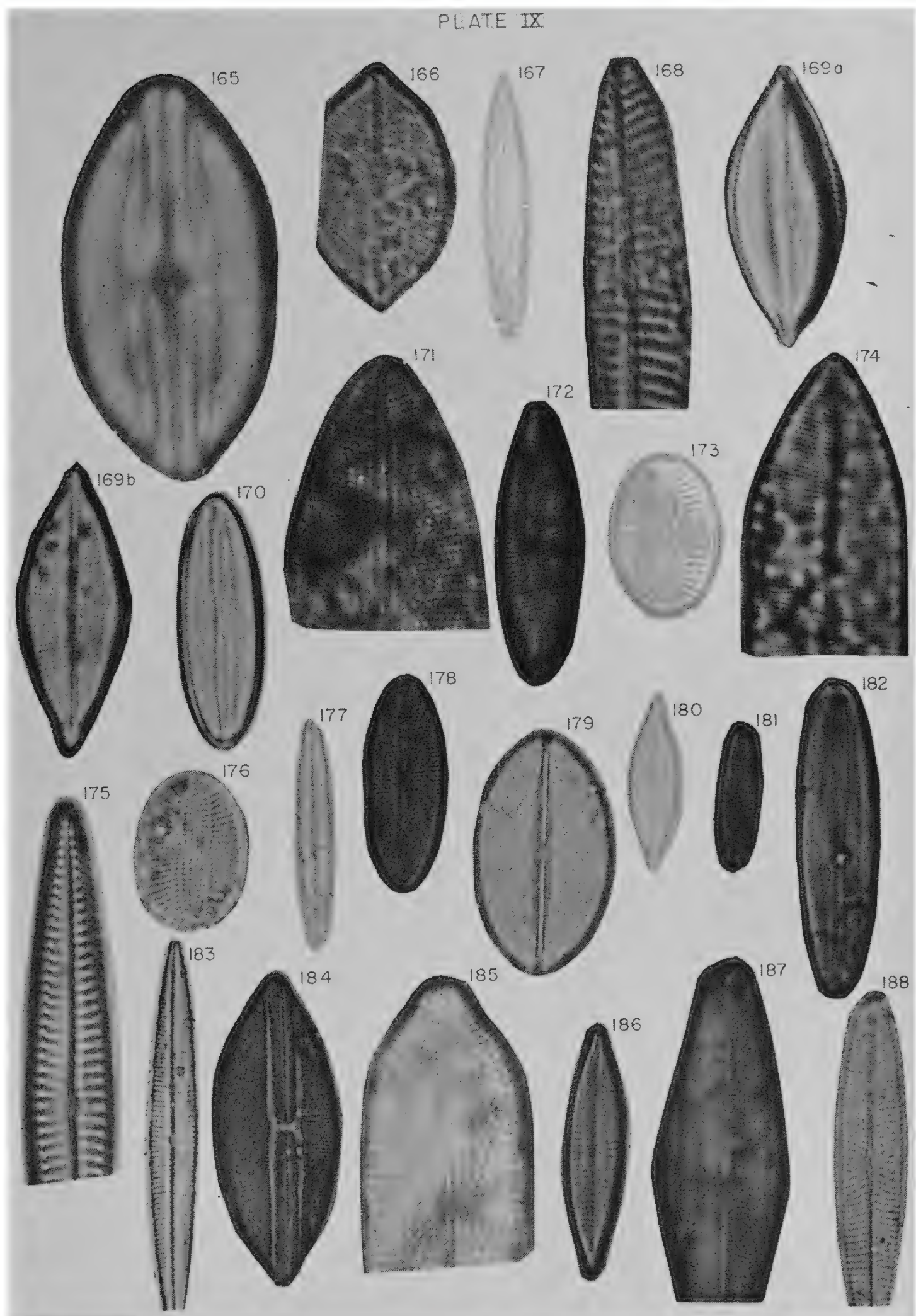


Plate 10.

Fig. 189. *Navicula zostretii*; Fig. 190. *N. elegans*; Fig. 191 a,b. *Nitzschia acicularis*; Fig. 192. *N. constricta*; Fig. 193 a,b. *N. distans*; Fig. 194. *N. gracilis*; Fig. 195. *N. granulata*; Fig. 196. *N. hungarica*; Fig. 197. *N. longissima*; Fig. 198 a,b. *N. lorenziana*; Fig. 199. *N. mediterranea*; Fig. 200 a,b. *N. obtusa*; Fig. 201. *N. palea*; Fig. 202. *N. panduriformis*; Fig. 203. *N. plana*; Fig. 204. *N. punctata*; Fig. 205. *N. sigma*; Fig. 206. *N. silicula*; Fig. 207. *N. tryblionella* v. *victoriae*; Fig. 208. *N. sp.*; Fig. 209. *Opephora pacifica*; Fig. 210. *O. schwartzii*; Fig. 211. *Pinnularia viridis* v. *rupestris*; Fig. 212. *Plagiogramma obesum*; Fig. 213. *P. wallichianum*; Fig. 214 a,b. *Pleurosigma angulatum*; Fig. 215. *P. balticum*; Fig. 216. *P. beaufortianum*; Fig. 217. *P. distortum* v. *diaphana*.

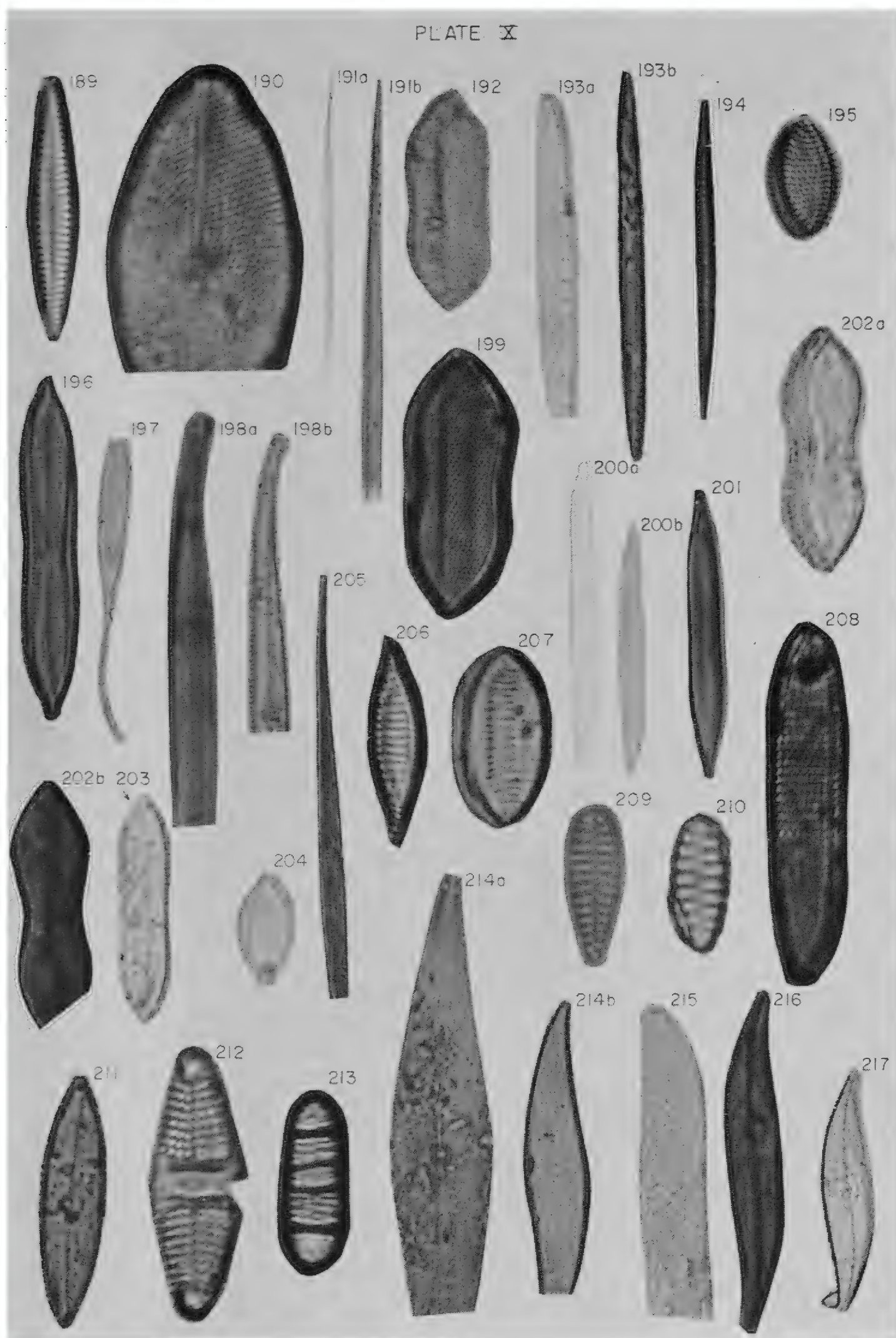


Plate 11.

Fig. 218 a,b. *Pleurosigma distinguendum*; Fig. 219. *P. fasciola*; Fig. 220. *P. formosum*; Fig. 221. *P. naviculaceum*; Fig. 222 a,b. *P. peisonis*; Fig. 223. *P. simile*; Fig. 224 a,b. *Podosira hormoides*; Fig. 225. *Pyxidicula cruciata*; Fig. 226. *Rhabdonema adriaticum*; Fig. 227. *Rhaphoneis ampiceros*; Fig. 228. *R. castracanei*; Fig. 229 a. *R. surirella*; 229 b,c. *R. surirella* v. *australe*; Fig. 230 a-d. *Rhopalodia gibberula*; Fig. 231 a. *R. musculus*; 231 b. v. *constricta*.

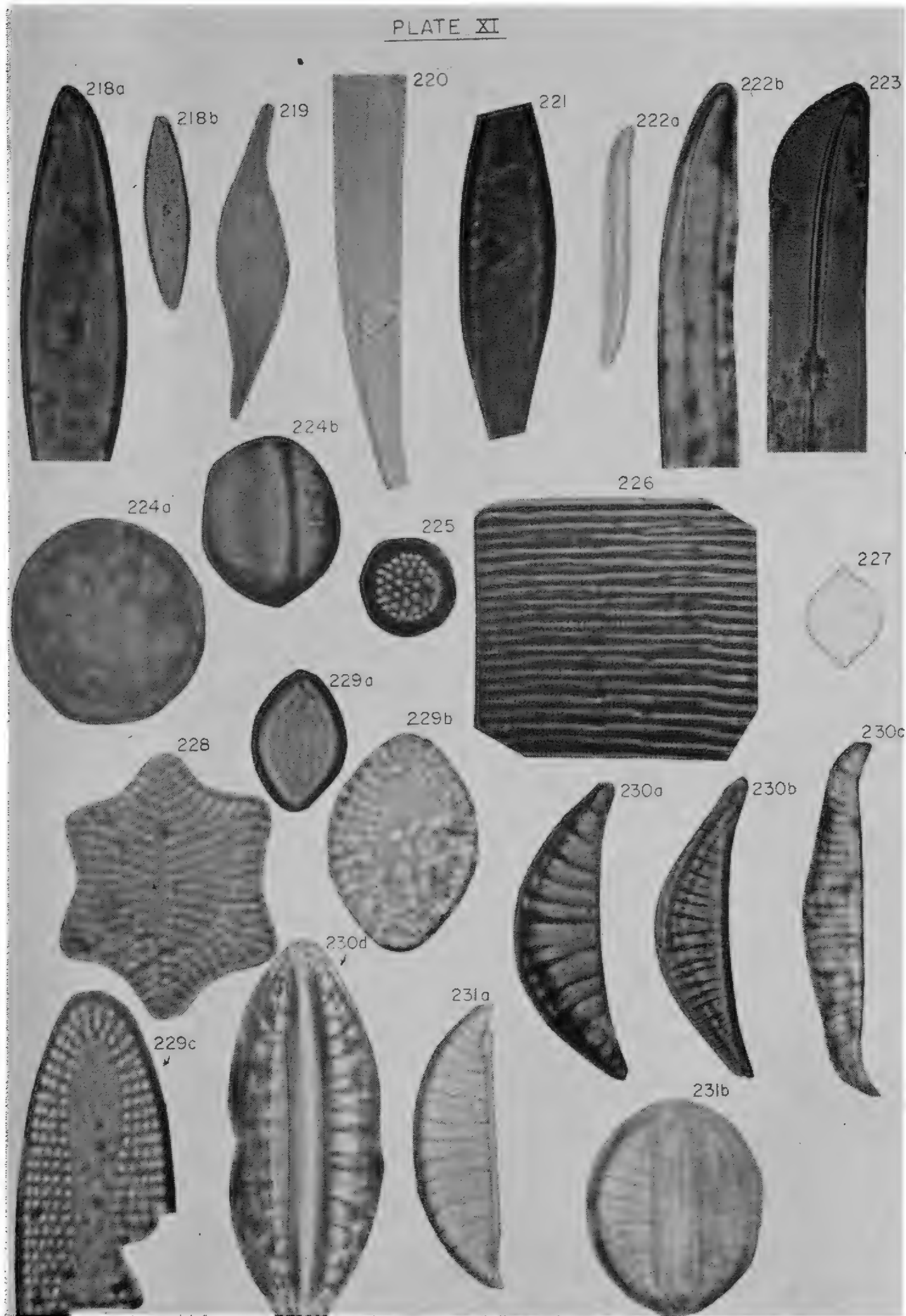
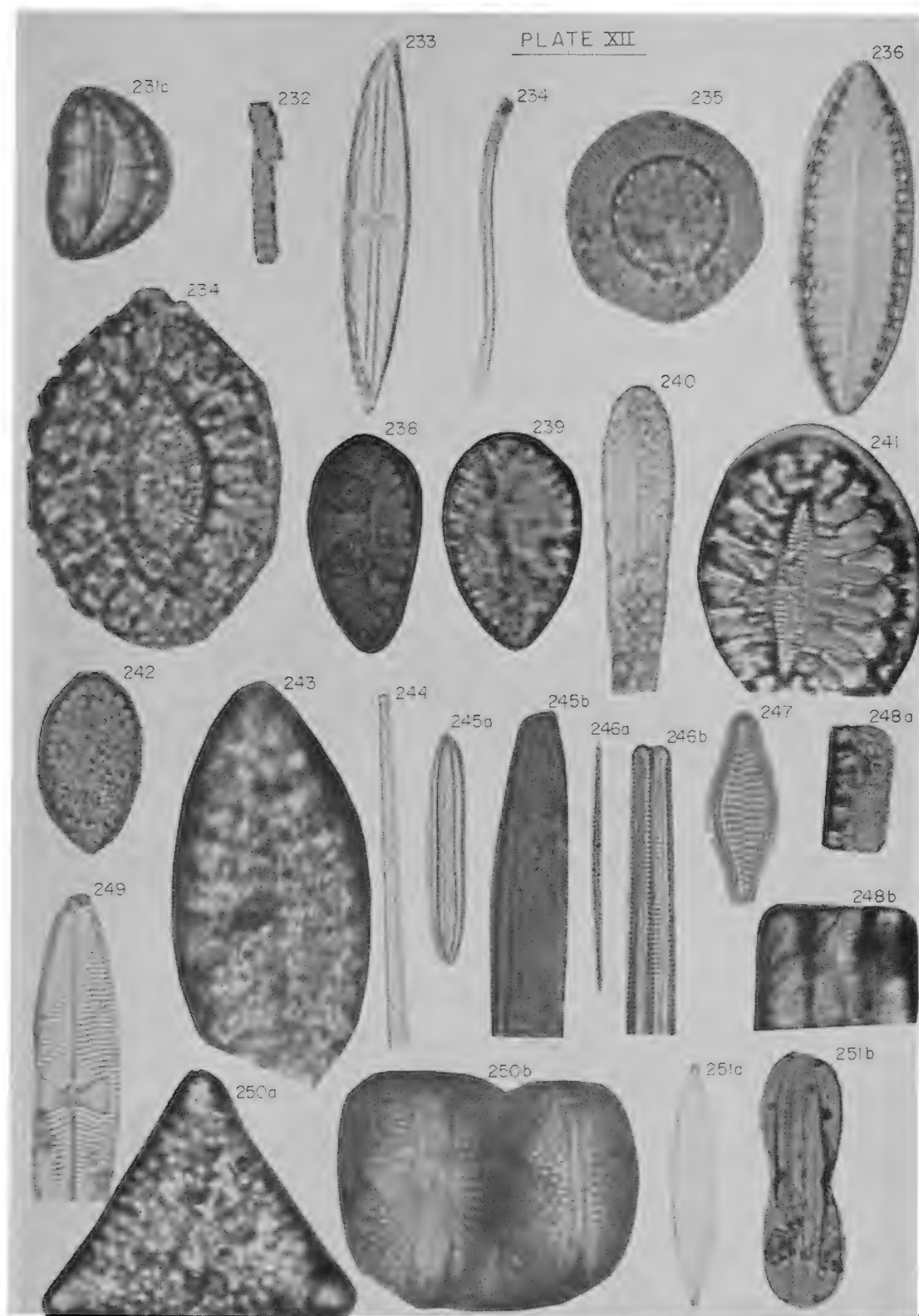


Plate 12.

Fig. 231 c. *Rhopalodia musculus* v. *constricta*; Fig. 232. *Skeletonema costatum*; Fig. 233. *Stauroneis phoenicenteron*; Fig. 234. *Stenopterobia intermedia*; Fig. 235. *Stephanodiscus dubius*; Fig. 236. *Surirella biseriata*; Fig. 237. *S. fastuosa*; Fig. 238. *S. fluminensis*; Fig. 239. *S. ovata*; Fig. 240. *S. patella*; Fig. 241. *S. recedens*; Fig. 242. *S. regina*; Fig. 243. *S. striatula*; Fig. 244. *Synedra acus*; Fig. 245 a,b. *S. formosa*; Fig. 246 a,b. *S. ulna*; Fig. 247. *Trachysphenia acuminata*; Fig. 248 a,b. *Terpsinoe americana*; Fig. 249. *Trachyneis aspera*; Fig. 250. *Triceratium reticulatum*; Fig. 251 a,b. *Tropidoneis lepidoptera*.



References

The list of references given here are those mainly used in the preparation of this paper, and which are desirable for a student working on the diatomaceae of the region. The reader is referred to Mills Index and to Wood, 1963 for more detailed bibliographies of the diatomaceae.

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Shallow Marine Sediments Offshore From the Brazos River, Texas¹

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Abstract

Bottom sediment from a 750-square-mile area offshore from the mouth of the Brazos River, Texas, has been analyzed statistically to determine the pattern and processes of sedimentation of the neritic environment and of a modern delta. The Brazos delta is characterized by topset beds of poorly sorted laminated sand, silt, and clay, foreset beds dipping at approximately 1° composed of fine sand grading downward (seaward) into clay, and poorly developed bottomset beds representing slow deposition of clay from the Brazos combined with reworking of material from a submerged Pleistocene deltaic plain.

Interpretation of the sediment on the basis of its modal characteristics indicates that effective sorting by waves develops a unique uniform distribution of sediment types from the beach to a depth of 60 feet. Farther offshore from this depth exotic agents such as hurricanes and uncharted bottom currents are predominant and act to bring "obstacles" (topographic irregularities) into a marine profile of equilibrium. Maps of sediment types, mean size, inclusive standard deviation, inclusive skewness, and kurtosis precisely describe the geologic history of the surface sediments. Individual and bivariate plots of the statistical parameters are shown to be useful in determining direction to the shoreline as well as completely defining the modality of the sediment, which in effect defines the environment of deposition. Fluctuations in source area are reflected by the relation of mean size and depth.

Heavy mineral distribution shows that the suite of durable minerals carried by the present Brazos River is diluting an existing widespread suite of less durable minerals characteristic of the Colorado River drainage area. Variation in clay mineral composition results from differential sedimentation and reflects source area, providing no evidence of alteration of the clay minerals during deposition by diagenesis.

Introduction

The shallow marine sediments included between the beach and the 100-foot depth-contour of the area offshore from the Brazos River, Texas (Fig. 1) are representative of the transition zone of shallow neritic deposition, a neglected area of study. In this setting one finds a wide range of textural sediment types with the corresponding wide range of grain-size parameters. The area is therefore well suited to the primary purpose of this paper which is to evaluate the significance and usefulness of statistical sedimentary parameters related to grain-size.

This region also affords the opportunity to study delta formation under nearly balanced conditions of marine and river interaction in contrast to the situations off the Mississippi River where river action is entirely dominant over marine action and the situation off the Colorado River, Texas, where marine agents are dominant. In 1953

¹ From a dissertation presented to the faculty of the Graduate School of The University of Texas in May, 1958, in partial fulfillment of the requirements of the degree of Doctor of Philosophy in Geology. Field studies were conducted from the Institute of Marine Science at Port Aransas, Texas, in 1955 with the aid of a grant from the Mobil Oil Company.

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W. I. Odem studied the sediments (1953a) and subaerial aspects (1953b) of this delta. Results of these studies will be noted herein. C. C. Bates (1953, p. 2155–57, Fig. 7) described changes in the subaerial part of the delta studied here as they are shown by a series of aerial photographs from 1938 to 1949 but did not discuss the history of the delta in detail.

Bullard (1942) has studied the beach sands along the entire Gulf Coast and interpreted the sedimentation patterns. Lohse (1952) analyzed the shallow marine sediments included within the 10 fathom line from 20 nautical miles north to 71 nautical miles south of the Rio Grande. Shepard and Moore (1955) and Shepard, Phleger and Van Andel (1960) have summarized the American Petroleum Institute Project 51 studies of recent sediments of the central Texas coast; but their detailed work is largely confined to the bays in the Rockport area. Numerous persons and agencies have been studying the Mississippi River delta and associated area for many years. An excellent bibliography, prepared by Geyer (1950) lists all papers dealing with the Gulf of Mexico. The present study deals with the shallow marine sediments offshore from the mouth of the Brazos River.

DESCRIPTION OF THE AREA

The area of investigation is located in the northwestern Gulf of Mexico offshore from the mouth of the Brazos River; Freeport is a few miles inland and served as a base for field operations. Cedar Cut, which appears on United States Coast and Geodetic Survey charts, but which is presently nonexistent, marks the southwestern limit of the area, and Oyster Cut, also nonexistent at present but shown on charts, marks the northeastern boundary of the area. The beach and the 100-foot depth-contour mark the shoreward and seaward boundaries respectively. The area extends about 25 miles alongshore and about 30 miles out to sea, including 750 square miles within these limits. In addition, the beach northeast to San Luis Pass and southwest to Brown Cedar Cut was covered by jeep, and the Brazos River was examined for some distance upstream.

Submarine Topography. Bottom topography of the study area is illustrated in Figure 2, which was constructed from the original work sheets (smooth sheets) of the U. S. Coast and Geodetic Survey. The topography of the area, in particular the highs, must constantly be borne in mind throughout this work as it exerts a dominant influence on the sedimentary pattern.

The submarine extent of the Brazos River delta shows as a marked salient deflecting the 50-foot depth-contour and is symmetrical in its configuration. This symmetry is interesting in view of the presence of a well established southwest longshore current (Bullard, 1942, p. 1037), and will be discussed later in relation to the subaerial delta of the Brazos.

Approximately 7 to 8 miles offshore from the mouth of the Brazos a string of highs appear which Mattison (1948, p. 77–78) described as coral heads. Price (1953, p. 52) noted the occurrence of “scattered submerged coral heads on the salt-dome-like submerged mounds” along the shelf margin slope “south of Louisiana and off parts of the Texas coast,” and further stated that they probably are “cobble-like accumulations of algal bodies.” Nevertheless, the anomalies just off the delta, which are included inside the loop of the 60 foot contour and from which sediment samples were collected, do not fall into this category. They consist of about half and half by weight of oyster shell fragment and sand. All these features are surrounded by clay. They might also represent

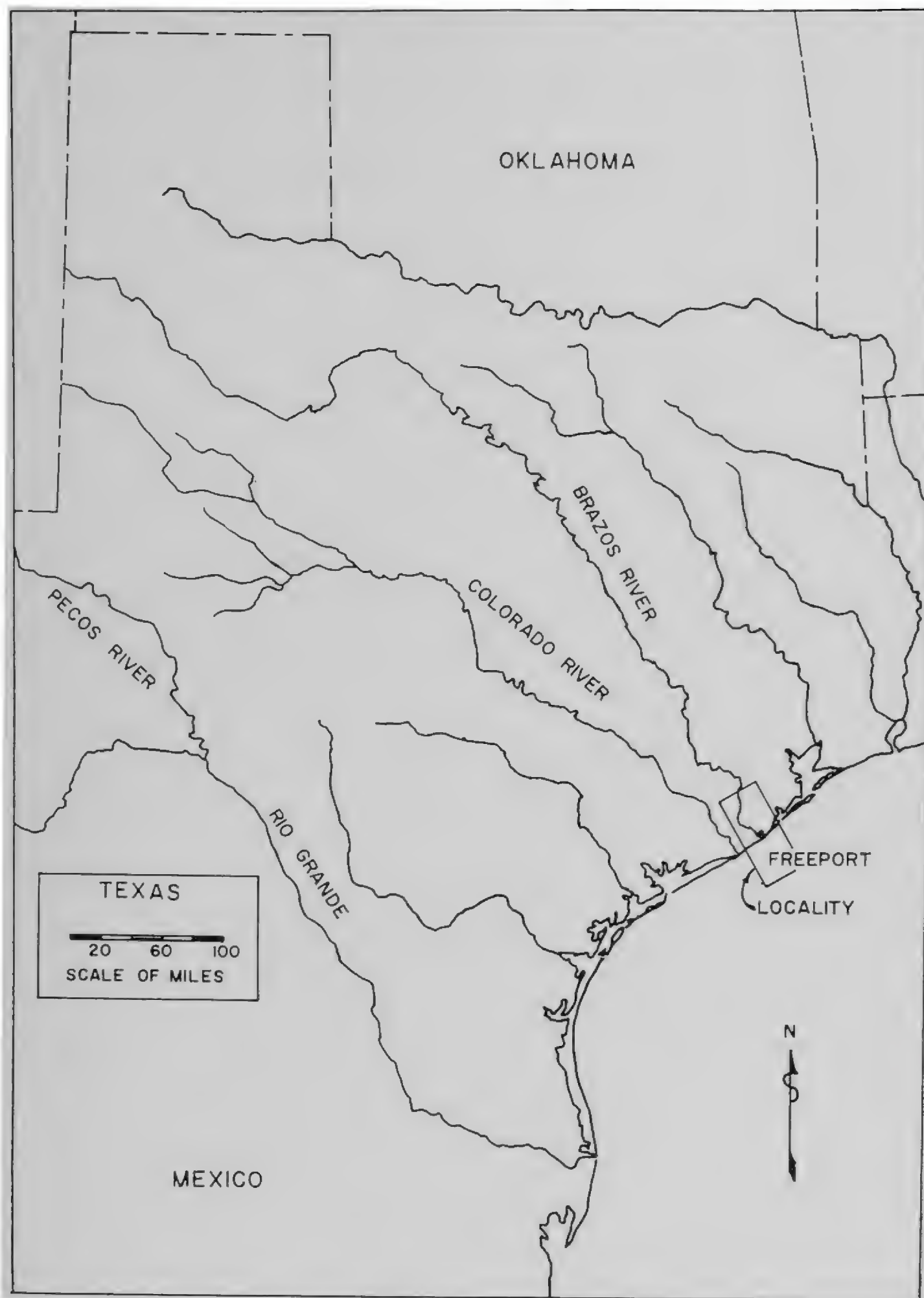


FIG. 1. Vicinity map showing location of the area studied on the coast of Texas.

offshore bars, or remnants thereof, buried beach ridges, or erosional remnants resulting from incomplete grading (smoothing) of older deposits by wave action. Recently Curray (1960) has mapped this prominence as a "depositional ridge."

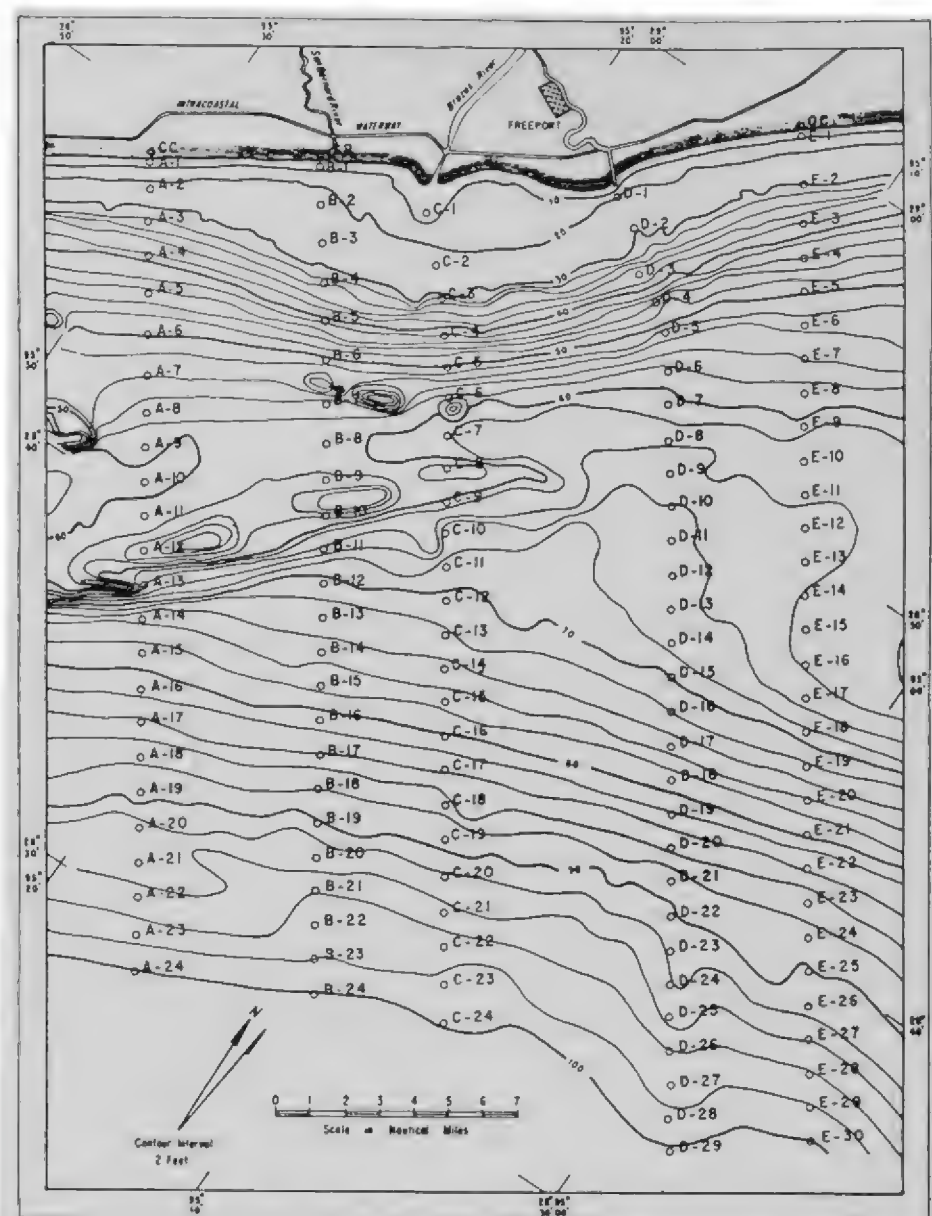


FIG. 2. Bottom contour map of the area of investigation, showing traverse and sample locations.

A pronounced break in slope occurs in the vicinity of the 60 foot contour where an abrupt broadening followed by a gentler gradient to the 100 foot contour is evident. From contoured smooth sheets of the adjacent areas, this shoaling is observed to disappear a short distance to the southwest and to broaden drastically to the northeast. Price (1953, p. 92-93) described part of this feature as a submerged young deltaic plain extending roughly east-west between the meridians of the Brazos River and Terrebonne Bay. He credited its existence to large offshore deltaic deposition, in part subaerial, of the Mississippi, Red, Sabine, Neches, Trinity, and Brazos Rivers and further noted that wave and current action now prevent streams west and southwest of the Mississippi from building deltas more protruberant than the arcuate Brazos-Colorado and Rio Grande deltas, not considering in this statement the tiny cusped delta of the post-1928 Brazos mouth.

In the geo-oceanographic classification (Price, 1953, p. 52B) this section of the coast is classified as a "Much Entrenched and Widely Embayed Compound Deltaic Plain." Price outlined this classification as follows (1953, p. 54) :

"Large rivers brought sediments from continental interior and inner parts of coastal plain during Pleistocene to form subaerial delta plains of low slope (now warped to 0.5 to 5.0 feet/mile for the younger ones and up to 20.0 feet/mile for the older) at high, interglacial sea-levels; delta fans merge lat-

erally, overlap toward the coast; active marine deltas on major streams; bay-head deltas in drowned, entrenched and shallowly but broadly embayed valleys of lesser rivers. Bays enclosed by barriers. Some drowned deltas out on shelf."

A few remarks concerning the marine profile of equilibrium for this area are in order. Only a brief explanation of the multiple factors involved is given here, and for a more detailed discussion the reader is referred to Price's excellent papers on this subject (1954a, p. 39-62, 1954b, p. 75-107, and 1953, 111 p.), and also to Kuenen (1950, p. 302-310). For the sake of uniformity the nomenclature proposed by Price (1953, p. 84-87 and 1954a, p. 59) is used.

The concave profile extending 1, 2, or possibly 3 miles from the beach or shore to a depth of 15 to 30 feet (and in a few exceptions 50+ feet) is termed the *shoreface*. The shoreface grades into a nearly smooth plain known as the *ramp*, which is characterized by a generally uniform gradient extending seaward commonly to 30 fathoms or more. The ramp in turn grades into a terminal convex section referred to as the *camber*, which extends to the continental slope at which point the gradient increases rapidly and often irregularly.

Grading, which includes erosion, is characteristic of the shoreface, grading and transportation of the ramp, and deposition of the camber. At the foot of the steep shoreface, the profile may show a mound and corresponding depression. Price (1953, p. 15A) calls this feature the *saddle*. As the area under investigation does not extend to the camber, only the shallower portion of the profile of equilibrium will be considered further.

The curve of the combined shoreface and ramp (or shoreface-terrace curve) describes a hyperbola. The theoretical curve for the steepest bottom over which waves will move without breaking, and therefore without eroding, is also a hyperbolic function (Keulegan and Krumbein, 1949), wave depth being the $4/7$ power of the distance from shore.

The previously mentioned erosion that takes place on the shoreface accounts for planation of the beach. Maximum erosion probably occurs above a depth of 25 to 30 feet, a mean value determined by Dietz and Menard (1952, p. 2011). When sufficient smoothing of the shoreline has occurred, longshore currents attain importance and further serve to smooth the profile by deposition and transportation parallel to the shoreline.

Erosion also takes place on "obstacles." These include (Price, 1954b, p. 90) "(a) elevations standing above the general ideal shelf gradient (ramp-camber), and (b) very broad shoals approximately on the general shelf gradient." In the specific area under study the submerged deltaic plain qualifies as an elevated obstacle and is being graded to fit the profile of equilibrium.

The equilibrium profile is continually adjusting to its energy environment by means of erosion and deposition, and different equilibrium profiles are anticipated for different energy circumstances. Far from nullifying the value of the concept this dynamic factor becomes inversely significant because it allows the mapping (identification) of different energy environments by means of quantitative evaluation of equilibrium profiles. Care must be taken, however, to judge how closely the existing profile approaches equilibrium conditions. In unconsolidated material adjustment is rapid. Prograding of beach ridges in the present cycle is proceeding at a slower rate than at previous stages in their history.

The shoreline salient produced by the Brazos River delta was probably caused by ter-

restrial agents rather than marine agents. Further offshore the protuberance represents a region of both marine erosion and deposition. Valleys entrenched in this area during the last major Pleistocene lowering of sea level have been filled and deltas are forming at the expense of the stable bottom profile.

Topographic profiles of the study area are illustrated in Fig. 3. Traverses A and E (off Cedar Cut and Oyster Cut respectively) show a marked concave *shoreface* extending from the beach to a depth of 30–40 feet. This feature grades into a narrow *ramp* characterized by a nearly uniform seaward gradient. Obvious shoaling at a depth of approximately 60 feet indicates that a stable profile of equilibrium has not yet been achieved. Small *saddles* also occur at the base of the shoreface and most likely reflect slumping. Profile C (off the mouth of the Brazos River) exhibits a convex adjustment of the shoreface to accommodate the delta.

The energy pattern for the northwestern Gulf of Mexico may also be summarized in the manner indicated in Figures 4, 5 and 6. Similarity between the several sets of data is marked, of course, but the wave power approach is more refined and does seem to account for the sedimentary pattern of the area in a superior fashion. A surplus of energy is indicated from the south (impinging obliquely on the coast) and may serve to counteract to an extent the counterclockwise longshore current.

Geology and Climate of the Adjacent Land Area. The area directly under investigation is in the submerged Coastal Plain Province and must have been entrenched by the valley of the Brazos River, now completely filled. The land area directly adjacent to the shoreline consists of Recent deposits overlying eroded Lissie and Beaumont clays of Quaternary age which dip to the coast uniformly at approximately 0.5° .

This portion of the Texas coast is moist subhumid and receives approximately 45 inches of rainfall per year. The average yearly temperature is 20.8°C (approximately 68°F), seldom exceeding 100°F during the summer months. Evaporation and precipitation are roughly equivalent and the prevailing wind direction is southeast.

BRAZOS RIVER

The Brazos system presently heads at an elevation of 4000 feet in the Llano Estacado of the High Plains in New Mexico just west of the Texas-New Mexico state line. Double Mountain Fork, Salt Fork, and White River in West Texas are the chief tributaries giving rise to the Brazos River proper. It flows in a general west-east direction with a length of approximately 1300 miles and drains an area of roughly 45,000 square miles. Prior to capture by the Pecos River (Baker, 1915, p. 53–54, and Tenth Annual Report of the State Engineer, 1930–1931, New Mexico) tributaries of the Double Mountain Fork of the Brazos extended into New Mexico and eventually drained the southern end of the Sangre de Cristo Mountains and swung south through Portales Valley, which is now an abandoned channel. This valley also received the present headwaters of the Pecos.

Because of the porous rocks which cover the Llano Estacado and the semi-arid climate, the sparse rainfall is quickly absorbed or evaporated, and the streams of the area are intermittent or relict. Consequently, this part of the Brazos River system, comprising roughly one-fifth of the entire drainage area, rarely contributes water to the river system.

The Brazos passes from the High Plains (Llano Estacado) into the Osage Plains where it crosses the Dockum group of the Triassic and continues southeastward through extensive outcrops of Permian and Pennsylvanian rocks in northwestern and central

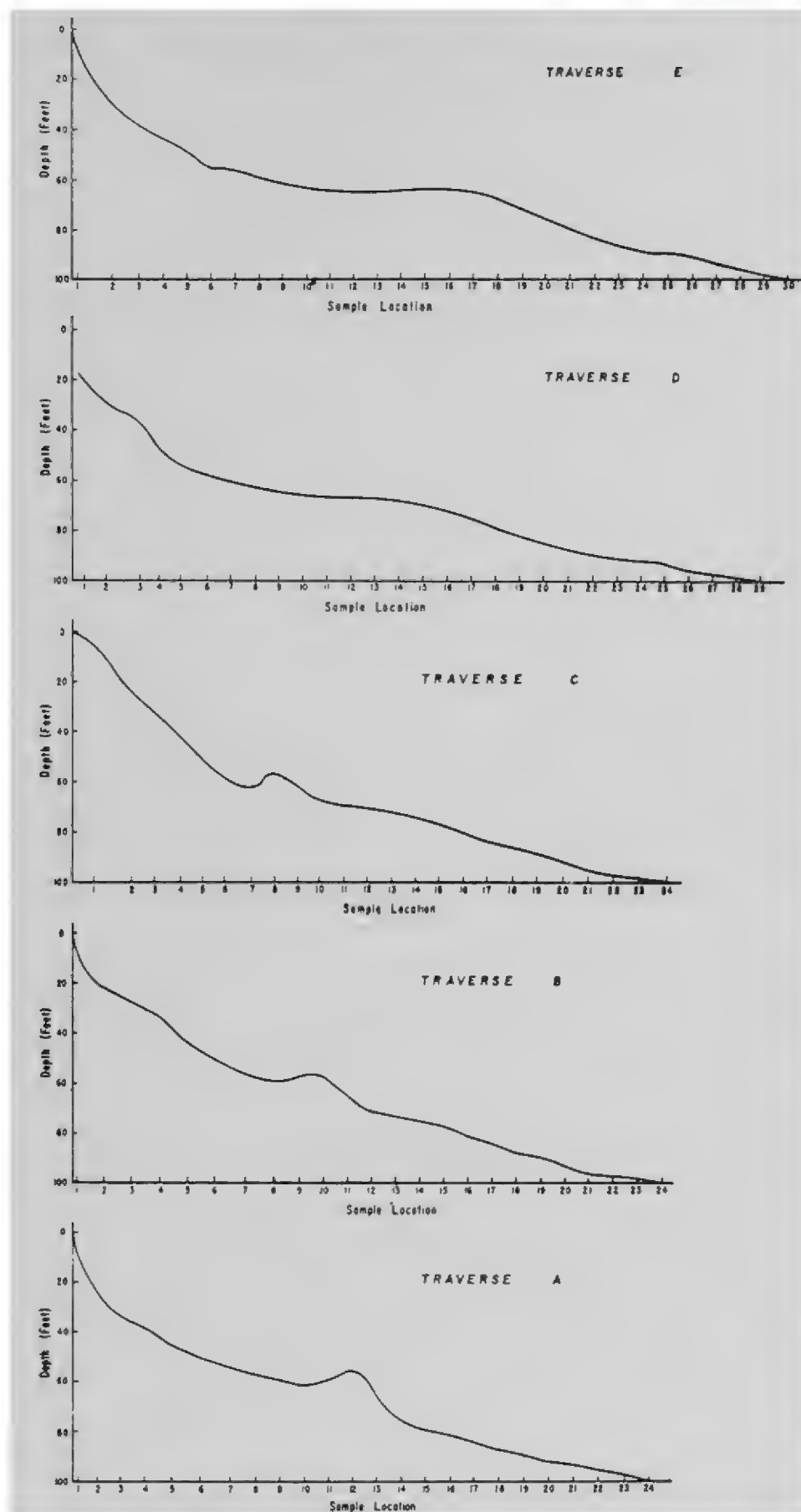


FIG. 3. Topographic profiles extending perpendicular to shore, traverse A and E marking, respectively, the southwestern and northeastern limits of the study area. Traverse C is directly off the mouth of the Brazos River.

Texas. The Triassic and Permian outcrops are predominantly composed of red sandstone and shale, and it is this contribution of red material to the Brazos that serves to color the river throughout the remainder of its course to the Gulf of Mexico.

The Pennsylvanian outcrop, composed largely of alternating shale and limestone, shows the greatest relief in the Brazos Valley.

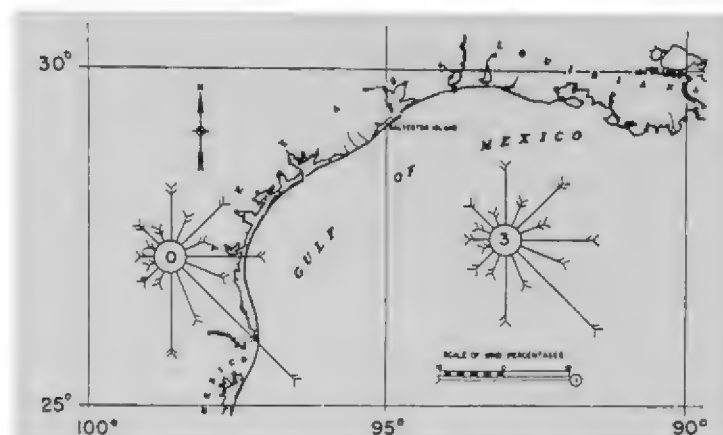


FIG. 4. Prevailing winds of the Gulf Coast. From U.S. Congress (1953). The wind rose in each 5° square shows the yearly average winds that have prevailed within that square. The arrows fly with the wind. The length of the arrow measured from the outside of the circle as demonstrated on the scale below gives the per cent of the total number of observations in which the wind has blown from or near the given direction. The number of feathers shows the average force of the wind on the Beaufort scale. The figure in the center gives the percentage of calms. Wind roses for 18-month period ending July, 1946 were compiled from "Pilot Charts of the North Atlantic Ocean" issued by the Hydrographic Office, U.S.N.

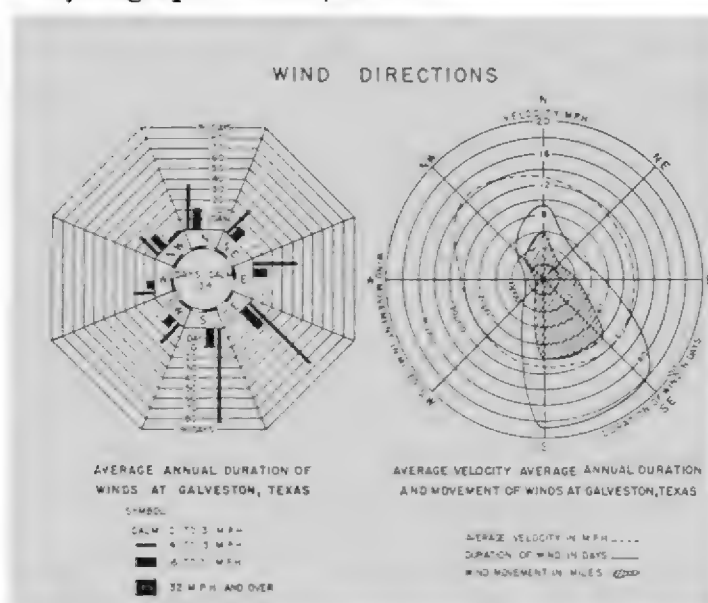


FIG. 5. Wind diagrams of the Gulf Coast. From U.S. Congress (1953). Based on hourly readings 1905-1944 by the U.S. Weather Bureau.

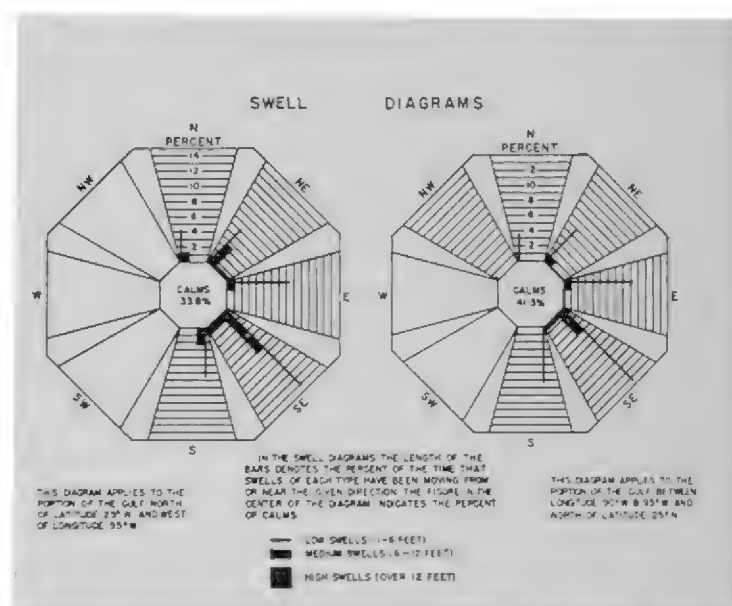


FIG. 6. Swell diagrams of the Gulf Coast. From U.S. Congress (1953).

Just below Mineral Wells the Brazos encounters Cretaceous rocks and continues on these for some distance below Waco. The Cretaceous outcrop consists chiefly of limestone and marl of the Comanche series and the Gulf series.

At Waco the Brazos crosses the Balcones fault zone and passes onto the Gulf Coastal Plain, which is composed of Tertiary sandstone and clay with a few thin limestone beds. At mile 160 the Brazos passes into the outcrop of the Quaternary Lissie and Beaumont clays and at Columbia, 40 miles from the mouth, into Recent alluvium.

The maximum width of the drainage area is roughly 120 miles in central Texas, whereas at the mouth it narrows to about 10 to 15 miles.

Brazos River Hydrology. The gradient of the Brazos River ranges from 6 feet per mile in the High Plains, where it heads at 4000 feet to essentially zero in its lowest reaches. Deussen (1924, p. 13) presents a longitudinal midstream profile of the Brazos River from Waco, Texas, to the mouth, and it is from this profile that the following observations concerning the stream gradient are made.

From mile 430 (Waco) to mile 260 (Eocene-Miocene contact) the gradient is locally variable but averages 1.27 feet per mile, and the Cretaceous and Eocene beds, across

which the river flows in this belt, have a regional dip of from 40 to 90 feet per mile. From mile 260 to mile 160 (Pliocene-Quaternary contact) the gradient is 0.65 feet per mile, the Miocene and Pliocene beds traversed have a regional dip of from 30 to 40 feet per mile. From mile 160 to mile 50 the gradient is 0.92 feet per mile in the Quaternary beds, which have a regional dip of from 20 to 30 feet per mile. Finally, the gradient is less than 0.1 feet per mile in the essentially flat lying Recent deposit from mile 50 to the Gulf, this portion of the stream course being tidal.

Several interesting observations may be made from the above calculations. First, a progressive decrease in the regional dip of the formations traversed is reflected in the stream gradient. Second, ultimate base level has progressed 50 miles upstream, the knick-point having traveled 10 miles beyond the Quaternary-Recent contact. Third, when the overall gradient from mile 160 to mile 0 is calculated it is found to be 0.66 feet per mile and thus is identical to that of mile 160 to mile 260. This same gradient is maintained up to mile 305, the base of the Upper Eocene. Therefore, an original uniform gradient existed for the lower 305 miles of the Brazos prior to headward transgression of base level. Fourth, a second knickpoint is observed at mile 160, the Pliocene-Quaternary contact.

The river profile is a result of river filling and cutting. During the last major lowering of sea level, at the close of Pleistocene time, the Brazos River entrenched itself across the Coastal Plain in a valley almost 200 feet deep and built a large offshore delta. The present Brazos River filled in its old valley almost completely and is in the process of building a new delta. The existing channel, therefore, lies in Recent fill, which the Brazos itself deposited.

River width and depth are locally variable but in general fit the idealized pattern rather well. Depth increases toward the mouth, being 25 to 30 feet below mean low tide at the Gulf. Width also increases toward the mouth to more than 500 feet. Flood plains are best developed in the last few miles before the Brazos enters the Gulf, extending roughly 5 miles on either side of the main channel. Natural levees on this section of the river are at the most 1 foot high. Rises at the mouth of the Brazos are in the order of inches, so that at the gauging station on the Intracoastal Waterway locks, floods are recorded by velocities rather than by measurements of increased river height.

Table 1 is compiled from Bloodgood and Mortensen (1951, p. 57-58) and summarizes discharge data for the Brazos River and other major Texas streams. The important figures are the yearly amount of silt in tons and the percentage of silt by weight. The

TABLE 1

Summary of silt data for some of the major Texas streams for water year ending September 3, 1950 (Bloodgood and Mortensen, 1951)

Stream	Silt station	Total length record	Average runoff of stream	Average amount of silt	Silt by weight	Net drainage area
		Years	Million acre-feet	Million tons	Per cent	Thousand square miles
Brazos	Richmond	26	5.69	34.74	0.448	34.81
Colorado	Columbus-E. Lake	7	3.17	8.99	0.209	29.14
Nueces	Three Rivers	23	0.67	0.76	0.083	15.60
Rio Grande	Roma	14	4.17	19.20	0.338	157.20
Sabine	Ruliff	1	11.41	5.77	0.037	9.44
Trinity	Romayor	14	6.66	6.62	0.073	17.19

average figure of 0.448 percent silt by weight for the Brazos is almost double that of any other Texas stream and is roughly 17 times larger than that for the Mississippi River (Odem, 1953a, p. 19).

Referring again to Bloodgood and Mortensen (1951, p. 57) it appears that the construction of Possum Kingdom Dam in 1942 served to trap silt from the upper reaches of the river, thus subtracting the upstream silt contribution from the river load. Prior to construction of the dam, Glen Rose gauging station recorded 0.794 per cent silt by weight, while Possum Kingdom Dam gauging station (below the lake) now records 0.016 per cent silt by weight. However, the pertinent fact is that the eventual discharge of silt into the Gulf has remained almost constant over the last 26 years (as recorded at Richmond gauging station). It may be concluded that most of the material being dumped into the Gulf of Mexico by the Brazos River is a product of bank erosion between Waco and the mouth.

Subaerial Delta.—The present subaerial delta of the Brazos River has been forming only since 1929 when the mouth of the river channel was diverted to a point southwest of the then existing mouth at Freeport Harbor. Since 1880 the lower 5 miles of the Brazos River course have been used as a salt water port. Freeport Sulphur Company shipped large tonnages of sulphur mined from Bryan Mound, just to the south of Freeport, until recently when it shifted its operation to Hoskins Mound from which the sulphur now moves by rail to Galveston. At one time 70 per cent of the U. S. production and 35 per cent of the world production of sulphur moved through Freeport Harbor. Since the diversion of the lower 7.3 miles of the Brazos River to the southwest (making the harbor tidal), Dow Chemical Company has made use of the harbor facilities.

Before 1929, with every rise on the Brazos the harbor silted up to non-navigable depths and had to be dredged. Considering the silt load carried by the Brazos during rises, 5 to 10 per cent by volume (Fox, 1931), and the fact that rises occur on an average of 5 times a year (10 times a year from 1920 to 1924, Odem, 1953a, p. 22), the problem can be envisioned. A reduction in harbor depth of from 25 feet to 12 feet during one flood is reported. Shoaling at the river mouth was another difficulty; channels shifted frequently and constant dredging was necessary.

In 1928, the decision was made to make Freeport a tidal harbor by diverting the river at a point above Freeport and leaving the old channel as a tidal lagoon in the hope that this would eliminate or cut down maintenance costs. By September, 1929, the diversion had been accomplished and the Brazos River then entered the Gulf of Mexico 6.5 miles southwest of Freeport Harbor. The new channel was 5.5 miles long (measured from the point of diversion 7.3 miles above the original mouth) and trended for the last 6000 feet at an angle of 63° to the shoreline. The upper portion of the diversionary channel was dredged to a width approximately equivalent to that of the river above the point of diversion (450 feet), while the lower extent was only about half this wide. Dredging was carried on to a depth of 12.5 feet with the spoil used to build levees on either side. A steel-reinforced earthen dam blocks off Freeport Harbor and completes the diversion.

The dredging operation served only to act as a guide for the river, which was left to scour its own channel. This the Brazos has accomplished rapidly, and flooding has been largely eliminated. Although rises do not cause the river to leave its banks, the area is inundated daily by high tide causing large marshy flats inland from the beach. The new

channel is showing no tendency to establish meanders such as existed in the old channel.

The effectiveness of marine agents and the dynamic state of shoreline development may be seen in a study of the shoreline adjacent to Freeport Harbor (Fig. 7). In 1887, prior to construction of jetties, the shoreline configuration was roughly comparable to that existing presently at the mouth of the diverted Brazos and the 3 fathom contour was well offshore. Following construction of the jetties between 1889 and 1908, rapid accretion occurred in the areas now protected from longshore currents on either side of the jetties. Prograding of the shoreline and seaward shifting of the 3 fathom contour on the east side of the jettied channel lagged behind that on the west side because of the drifting of the silt load, in deeper water, to the west. These conclusions may be inferred from the 1932 shoreline and 3 fathom contour. Southwest of the harbor jetties the shoreline advanced 4000 feet and the 3 fathom contour advanced 5000 feet. The corresponding shoreline and 3 fathom contour northeast of the jetties advanced 1800 and 1500 feet respectively. These data for 1932 are construed to represent maximum development of the Old Brazos River delta, as this is approximately the date of the diversion.

The abrupt cessation of river current and silt load caused by the 1929 diversion evoked a rapid change in the shoreline configuration between the harbor and the new river mouth. By 1946 the shoreline in this area had retreated 1300 feet and the 3 fathom contour occupied its 1887 position. Conditions on the northeast side of the jetties in 1946 show essentially no change from 1932. The 1952 shoreline, (not shown on Fig. 7), shows a further regression to a position coincident with the original 1887 shoreline (U. S. Congress, 1957), thus completing the cycle.

Following diversion in 1929, and the flood of 1930, a depth survey of the nearshore

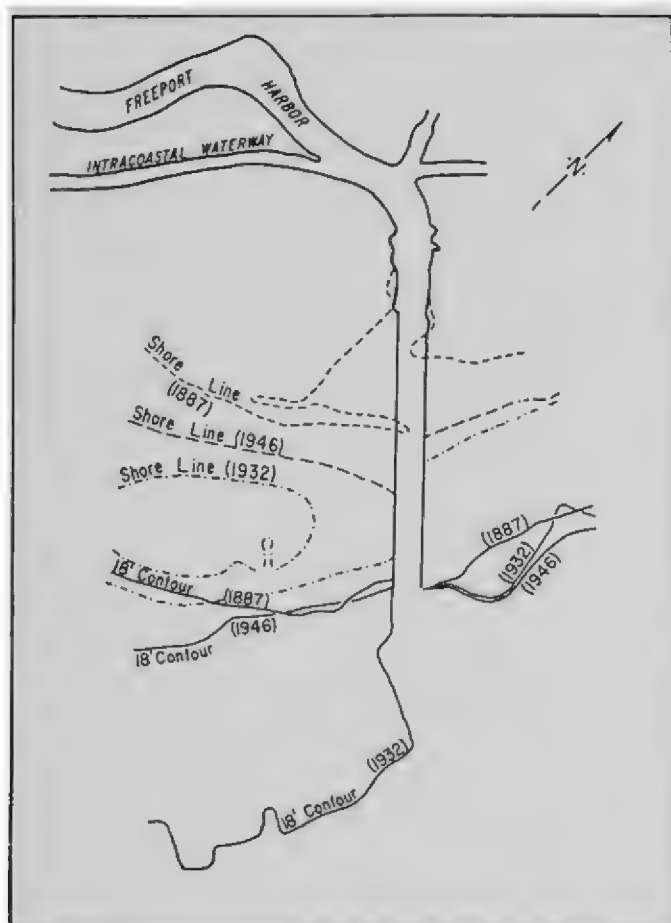


FIG. 7. Shoreline development adjacent to Freeport Harbor, Texas. Adapted from U.S. Congress (1948).

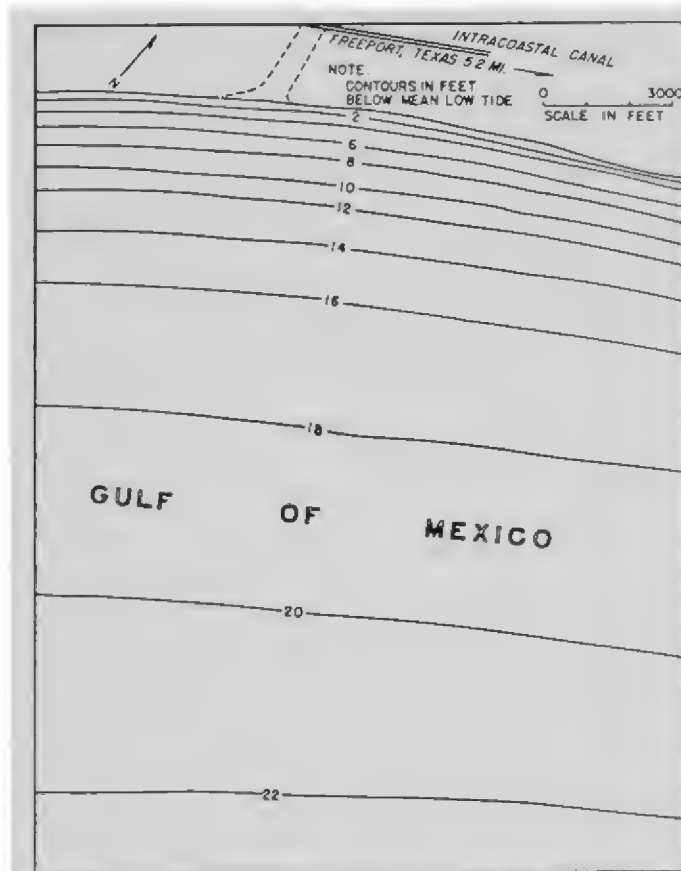


FIG. 8. Bottom contour map off the mouth of the Brazos River for 1929. From Odem (1953a).

area was made (Fox, 1931). From this survey maximum deposition was found to be about one-fourth mile offshore, well in front of the channel mouth. Depth surveys were subsequently made for the following 4 years by the Corps of Engineers in an effort to ascertain whether the channel would maintain itself or whether it would clog up. These surveys indicated that the crest of the delta was moving seaward at a rate sufficient to keep the channel clear.

The 1929 bathymetric map of the area off the mouth of the diversion channel (prior to diversion) shows a uniform depth increase offshore, with contours parallel to the shoreline (Fig. 8). From bottom contour maps for succeeding years the following observations are made. By 1931 (Fig. 9) the delta crest had moved seaward 3000 feet (2000 feet since 1930) and was 2 feet below sea level. Slight deposition over a wide area is shown by the 16 foot contour. The channel has already begun to swing southeast and the steepest face of the delta is also in this direction, as indicated by the closer spacing of the 6 through 14 foot contours. Irregularities in the contour configuration farther offshore are caused by rip currents.

By 1932 (Fig. 10), or 3 years after the diversion, the river deepened its channel and had developed a submerged distribution system, while the crest of the delta had advanced 3000 feet and was clearly defined by steep circumferential contours. Increased areal extent of the delta is obvious.

Portions of the delta became subaerial in 1933 (Fig. 11) and a symmetrical pattern had developed. Again, the southeastward trend of the main distributary channel has been progressively emphasized. Although areal extent has not increased significantly since 1932, the slope off the crest has become much more uniform. Most of the deposition during this interval has been nearshore, resulting in elevation of this part of the delta above water.

The changes in the delta are less clear on the map for 1934 (Fig. 12). Areas of the delta formerly subaerial are once again submarine; the main channel is not as well defined, and deposition has shifted in part to the adjacent northeast region. A less uniform slope and an advance 1500 feet seaward of the delta is partly due to a redistribution of sediment rather than any great increase of new deposits. Pronounced smoothing results in a marked parallel configuration of the delta face with the shoreline.

Isopach maps, employing the 1929 bottom contour as zero datum, indicate delta growth even more clearly. Initial rapid buildup establishes the channel and gives the delta rough form (Fig. 13), and when areal extent and vertical thickening have reached a balance, determined by the environment (Fig. 14), growth proceeds in a uniform manner in three dimensions (Fig. 15).

A flattening and gradual loss of character of the delta configuration developed by 1934 (Fig. 16). The orientation of the main channel has now shifted from southeast to due south and channels parallel to shore are well developed. The zero contour is considerably contracted, indicating a loss of areal extent, thickening has not only ceased but has actually decreased, and a loss in volume has probably occurred.

Development of the delta, as observed in the contour and isopach maps, may be conveniently explained in terms of the interaction of river current and silt load, and wave, tide, and current action (in other words, the environment). Assuming marine agents (waves, tides, and currents) to be reasonably uniform for the years 1929–1934, the explanation must be sought in variations in the Brazos River. Table 2 summarizes silt data

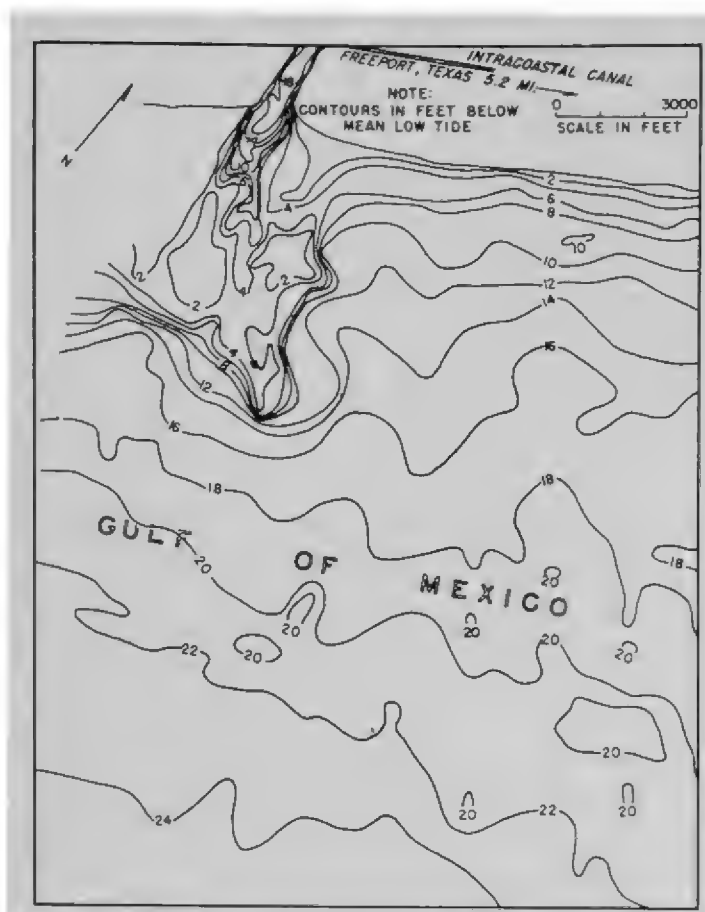


FIG. 9. Bottom contour map off the mouth of the Brazos River for 1931. From Odem (1953a).

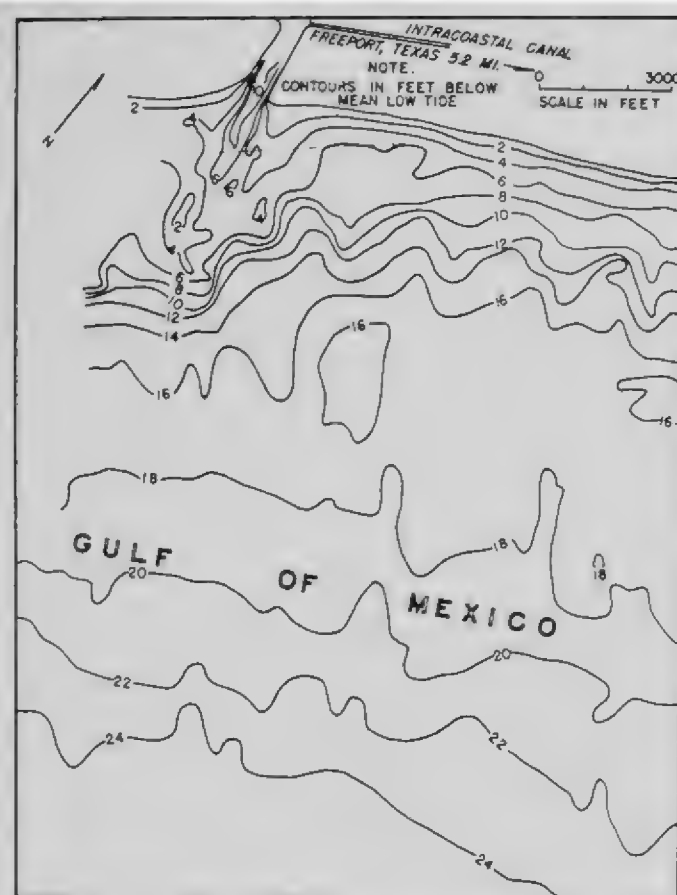


FIG. 10. Bottom contour map off the mouth of the Brazos River for 1932. From Odem (1953a).

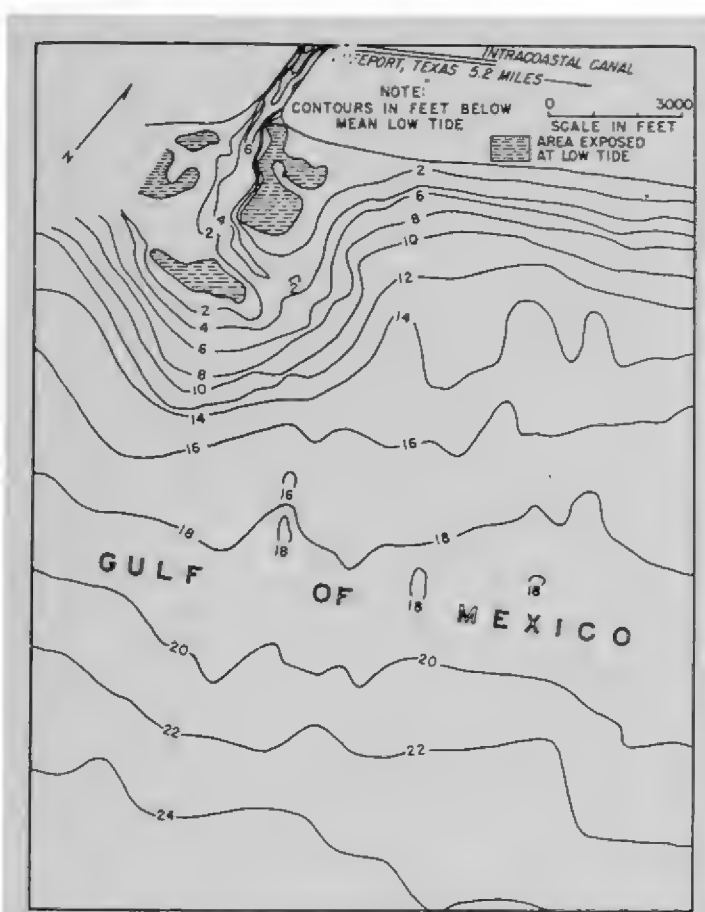


FIG. 11. Bottom contour map off the mouth of the Brazos River for 1933. From Odem (1953a).

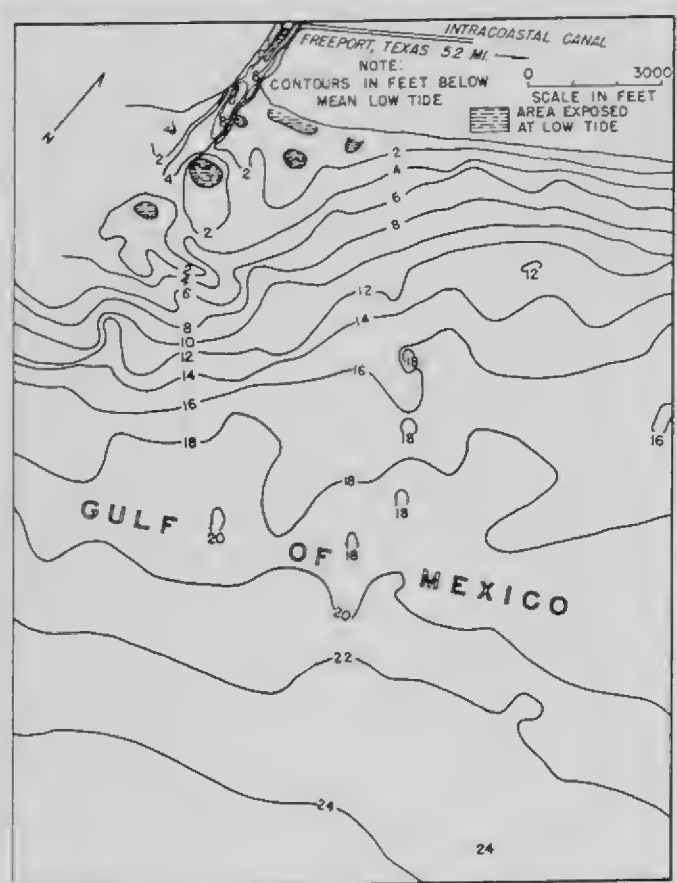


FIG. 12. Bottom contour map off the mouth of the Brazos River for 1934. From Odem (1953a).

for the Brazos River for the 4 years following the diversion. Water years refer to a calendar year of discharge measurements extending from October 1 to September 30.

Hydrographic surveys of the area were made in the early summer months, so that the 1931 survey represents conditions resulting mainly from the 1929-1930 water

TABLE 2

Summary of silt data for Brazos River watershed at Richmond gauging station
(Bloodgood and Mortensen, 1951)

Water year	Discharge of stream	Silt load of stream		Average percentage of dry silt by weight
	acre-feet	tons	acre-feet	per cent
1929-30	5,218,900	38,686,330	25,373	0.545
1930-31	5,639,000	27,766,660	18,212	0.362
1931-32	8,041,000	63,649,510	41,749	0.582
1932-33	2,563,100	15,175,520	9,954	0.435

year and so on. Thus, the water year of most abundant discharge, 1931-1932, accounts for the greatest development of the delta shown by the hydrographic survey of 1933. The marked decrease in discharge in the water year 1932-1933, correspondingly accounts for a redistribution and grading of the delta by marine agents as shown in the hydrographic survey for 1934.

Rapid adjustment to changes in dynamic equilibrium conditions are here illustrated in a graphic fashion. When the Brazos River discharge increased significantly, its share of the energy environment also increased significantly and delta growth accelerated. Conversely, when the Brazos decreased its discharge, its energy contribution correspondingly decreased, and marine agents attained a proportionately larger influence resulting in modification of the delta by these same agents.

The constantly accelerated rate of delta accretion since 1931 (75 per cent of the 1952 delta developed since 1942), indicates either that less and less of the silt load of the river is lost to longshore currents, or that longshore currents are unable to operate effectively against so impressive an obstacle and therefore dump their load on the delta.

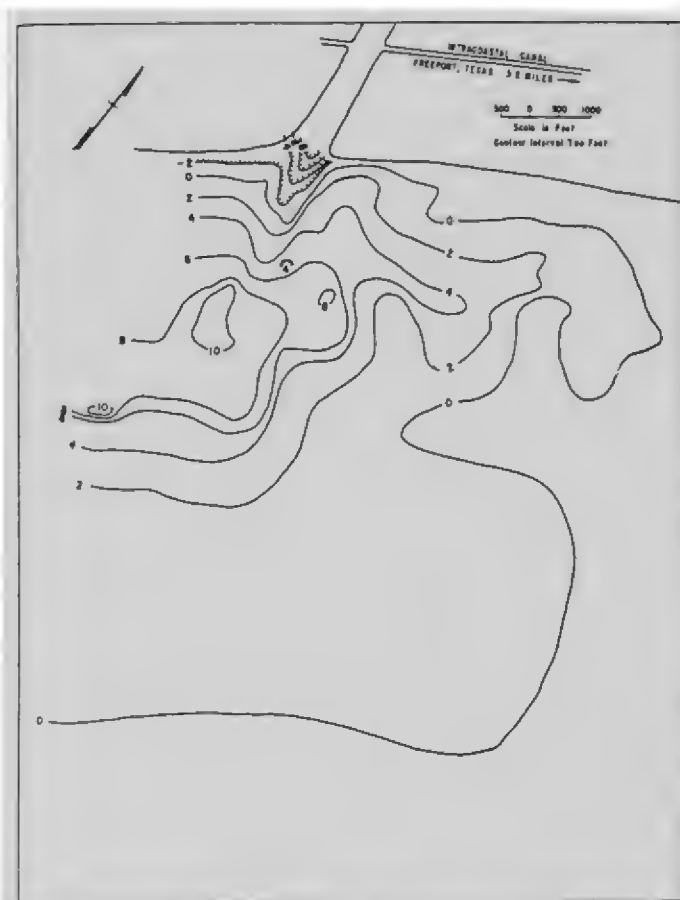


FIG. 13. Isopach map off the mouth of the Brazos River for 1929-1931. Adapted from Odem (1953a).

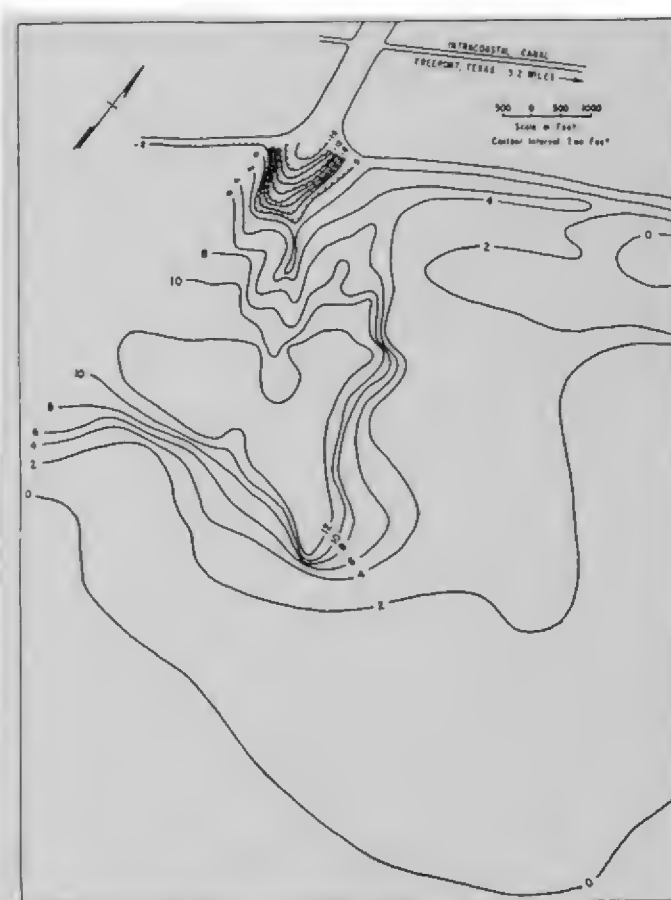


FIG. 14. Isopach map off the mouth of the Brazos River for 1929-1932. Adapted from Odem (1953a).

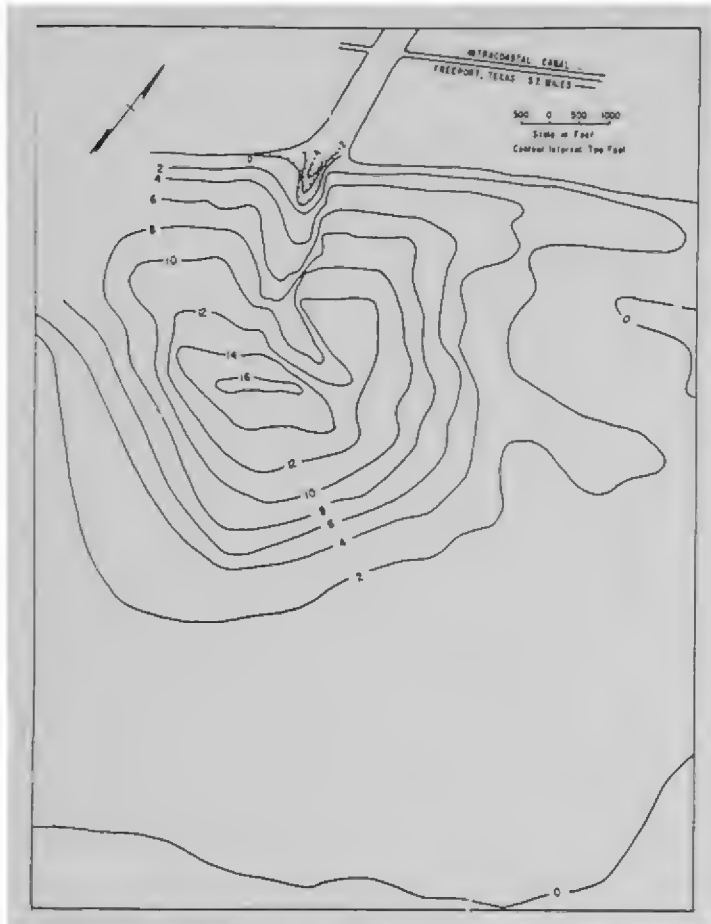


FIG. 15. Isopach map off the mouth of the Brazos River for 1929-1933. Adapted from Odem (1953a).

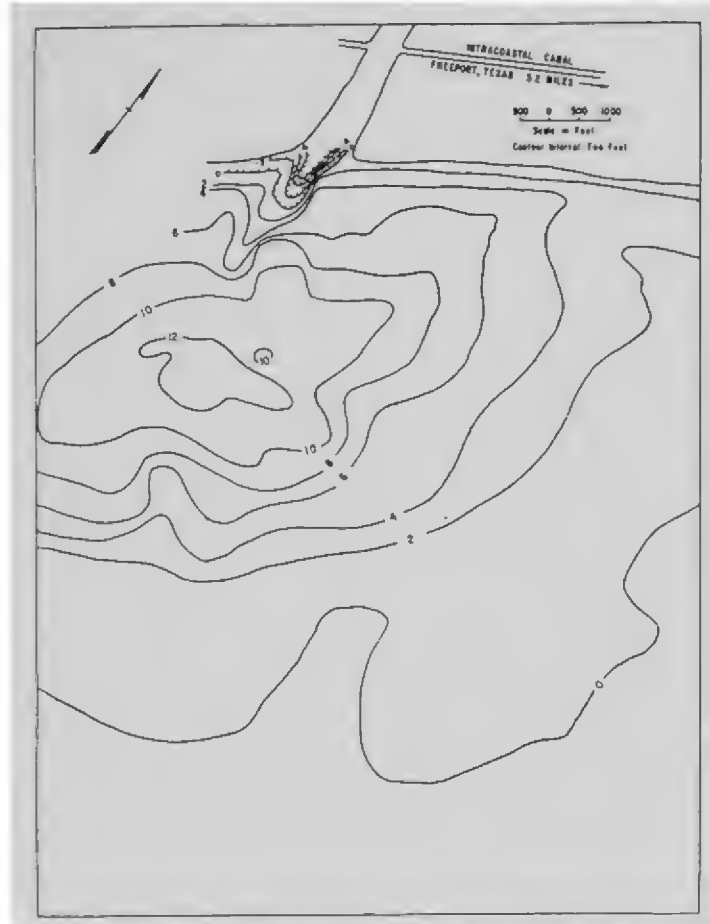


FIG. 16. Isopach map off the mouth of the Brazos River for 1929-1934. Adapted from Odem (1953a).

If at the present time longshore currents are agents of deposition rather than of transportation, it is a complete reversal of their original role.

Analysis of borings (Odem, 1953a, p. 87-88) reflects a permanent sedimentary record of vertical fluctuations in depositional history of the delta by intrastratification of different textural types. During periods of flood, coarse, poorly sorted material is deposited rapidly, but at times of low water, marine agents distribute layers of fine clayey and silty material over the entire region. Longshore currents deposit beach material on offshore bars and scour the channels between the bars. Although a major storm or hurricane may completely redistribute the upper fluid sediment layers in a matter of days, the pattern of extensive bottomset beds of fine material (evenly distributed by marine action) and foreset beds of coarser material (deposited by river action) is generally not distributed to the extent that the sequence is not readily identifiable.

At the time of the writer's study the subaerial portion of the delta exhibited well developed bars and spits on both sides of the mouth, and had an overall cusped appearance (Bates, 1953, Fig. 20). The main distributary channel is oriented approximately at right angles to the shoreline, an increase of roughly 22° over the original angle of intersection of the diversion channel with the shoreline. Hooked spits and barriers have grown to such an extent that they have enclosed lagoons behind them, and it is in connection with these lagoons that the action of tides becomes significant. Daily tides inundate the lagoonal areas, depositing fine grained material which eventually fills in the lagoons. The result is a more stable configuration of the delta and shoreline.

Figures 4 and 10 depict the several agents acting on the delta by means of quantitative energy approximations and explain adequately the symmetrical configuration of the present delta. Effects of longshore currents are not evaluated, but from other data it

appears that their contribution must be minor. Longshore currents have a dual role of transportation and deposition. Unquestionably, beach sand is being carried longshore in a southwesterly direction as concluded by Bullard (1942, p. 1042) and as indicated by the heavy mineral analysis of this report, but this fact should not be interpreted as signifying erosion and subsequent net removal of material to the southwest. Under uniform conditions only a certain limited amount of material can be transported at any specific time by a longshore current. As the current picks up material for transport it must then deposit a corresponding amount. Therefore, the actual net volume transfer of material at such a point may be zero, as is more evident when the mode of transportation of longshore currents is considered.

As pointed out previously, longshore currents are primarily agents of transportation, with the evidence indicating that the transported load moves primarily by traction and saltation. To roll or saltate a large sand grain possessing an *exposed* surface area is much easier than to pick up a very fine silt grain or cohesive clay flake and place it in suspension (Hjulstrøm, 1939, p. 10-11). Sargent Beach is a case in point; during periods of normal tides and moderate current conditions a thin veneer of sand covers the beach from high tide to some feet below low tide, but during periods of increased activity a hard slippery clay bottom is exposed. Erosion of this clay bottom is proceeding very slowly by a process of vertical caving in chunks, with mud balls being carried up onto the beach. Certainly at Sargent the clay material from the exposed bottom is not being picked up particle by particle and moved in suspension, nor, for that matter, is it even being eroded effectively. Contrast this situation in regard to the clay to the relative ease of movement of the sand veneer overlying it. This same clay bottom is exposed at low tide on either side of the Brazos mouth, its resistance to erosion and transportation accounting for the existence of straight sections of shoreline at these points. Only after enough sand has been deposited to bury the presently exposed clay will the shoreline become curved and fit the configuration of the delta in a more uniform manner.

From an examination of Fig. 4, 5 and 6 it may be concluded that almost all wave movement on the average is oriented directly onshore-offshore. This condition could be expected to give rise to locally and seasonally variable littoral drifts of low net magnitudes. The symmetrical configuration of the Brazos delta and adjacent shoreline, and of the present shoreline on either side of the Freeport Harbor jetties, substantiate this conclusion, as do wave refraction diagrams for the nearby Caplen, Texas, area (Beach Erosion Board, 1956). Bascom (1954) presents evidence indicating that stream outlets will shift in the direction of low wave attack, which would also be the direction of littoral drift. The main distributary channel of the Brazos River, however, has shifted from the southwest to a south-southeasterly direction, which circumstance, according to Bascom's reasoning, indicates a northeast longshore drift. Direct measurements of littoral currents and measurements of accretion, made by the Corps of Engineers on Galveston Island, have been interpreted by them as showing the existence of locally variable drifts, with frequent reversals of direction being common (U. S. Congress, 1953, p. 22-23).

On the other hand, petrologic evidence from Bullard (1942), and from this report (covered in a later section), indicate a net migration of material to the southwest. The nature of the movement of this material is conjectural as far as the study area is concerned. Mason (1953, p. 569) stated that for material moved by wave action, as much

as 80 per cent is moved in the zone between breakers and shore. Evidence presented by Trask (1931), in a study of sand movement around promontories in southern California, establishes the movement of sand parallel to shore in depths of water up to 60 feet. From a summary of recent studies concerning the rate of littoral transport (Johnson, 1956, p. 2217) it appears that maximum littoral transport occurs at a certain critical wave steepness which prevails for intermediate or summer waves and not for storm waves. The critical angle of wave approach with the shoreline for maximum littoral transport is approximately 40° (Johnson, 1956, p. 2217), considerably different than the prevailing angle of wave approach for the study area. Sediment characteristics also have an effect on longshore transport.

Evaluating all the evidence presented, the conclusion is reached that longshore movement of material in this area proceeds at some depth well seaward of the breaker zone. Furthermore some mechanism places this transported material into the zone landward of the breakers where it can be deposited on the beach by local littoral drifting. Longshore currents smooth shorelines by means of transportation and deposition, but the extent of their erosive power in this area is questionable.

SAMPLING AND ANALYSES

COLLECTION OF SAMPLES

Samples were collected in 1955 during the middle summer months when winds and storms are at a minimum. The Institute of Marine Science of The University of Texas, at Port Aransas, Texas, served as a permanent base of operations while field sampling was carried out from Freeport Harbor. The J 673, a 42-foot twin screw diesel launch converted from an Army air-sea rescue boat by the Institute of Marine Science, was employed in the sampling program. Sampling and navigation equipment was installed by the writer and the boat drydocked prior to putting to sea, for which the Mobil Oil Company very generously provided a grant.

A Bendix 400-foot, 400 fathom fathometer provided for a continuous depth record of all sample traverses. An outrigger davit was fabricated to handle sampling equipment in combination with a small hand winch. Bottom samples were secured with a Peterson grab sampler, a clam-shell device which is simple in construction and operation, is indestructible, and almost never malfunctions.

Sample locations are shown in Fig. 2, p. 000. There are five traverses normal to shore; from west to east they are: traverse A (off Cedar Cut which is no longer in existence but is indicated on hydrographic charts), traverse B (off the San Bernard River), traverse C (off the mouth of the Brazos River), traverse D (off Freeport Harbor), and traverse E (off Oyster Cut, also no longer in existence). Sample stations were determined by observation nearshore and by dead reckoning offshore, specifically, by compass bearing and boat speed after making necessary allowances for drift. This method proved entirely satisfactory as indicated by very close agreement of the bottom profiles with hydrographic charts. The pattern of widely spaced traverses of closely spaced sample stations (1 mile apart) provides for detailed profiles while at the same time establishing a grid pattern for spatial control of the entire area.

LABORATORY TECHNIQUES

Size Analysis. Size analysis was done following the hydrometer method utilizing the theoretical approach developed by Day (1950, 1953, 1956) in which the *effective depth* of an observed hydrometer (density) reading is calculated for the non-uniform suspension displaced by the hydrometer bulb. Values of effective depth calculated for the standard hydrometer 152H appear in ASTM tables for 1955. Procedure employed in analyzing samples for this report was as follows: Approximately 20 gram aliquots of raw sample were wet sieved through a U. S. No. 325 mesh screen, the coarse fraction washed to remove salt, dried, and sieved on the Ro-Tap for 15 minutes using a nest of screens employing a quarter phi interval. Visual estimations of shell and aggregates were made under a binocular microscope and subtracted from the measured weights (a necessary step in the interest of accuracy). All weighings were done on an analytical balance; fractions less than 1 gram being weighed to the nearest 0.01 grams. This order of precision is necessary when the cumulative curves are subsequently plotted on probability paper, which greatly expands the extremes.

The fine material washed through the wet sieve was retained, 2.55 grams of "Calgon" (sodium hexametaphosphate) added as dispersant, the mixture dispersed for 5 minutes in a malted milk mixer, and the sample plus enough water to make 1000 ml placed in a 1000 ml soil hydrometer jar. Sixteen hydrometer jars were lined up for hydrometer analyses to be run simultaneously.

Hydrometer readings were made at 1, 2, 4, 8, 15, and 30 minutes, and at 1, 2, 4, 7, 16, 24, and 48 hours, these times representing half phi intervals in the size distribution.

Data obtained from the sieving and hydrometer analyses are used to plot cumulative curves on arithmetic probability paper after the particle sizes have been converted to phi units. Statistical parameters are then calculated employing graphic values read from the cumulative curves.

Heavy Mineral Analysis. Aliquots for heavy mineral analysis were taken in such a quantity as to provide 20 to 30 grams of coarse material for subsequent bromoform separation. For some samples containing only a small percentage of coarse sizes, the aliquot was necessarily quite large. Clay was decanted from the raw sample, care being taken not to decant off any of the silt, as it was desired to obtain all of the heavies contained in the sample, not just those of a particular size grade. (The choice of which size grade to use in view of the large standard deviation of many of the sediments would be both difficult and questionable.) After oven drying of the coarse fraction, it was placed in a separatory funnel filled with bromoform, the heavy material (sp. gr. > 2.87) withdrawn, weighed, and reduced by means of an Otto Microsplit to a quantity suitable for mounting in Canada Balsam. The light fraction also was weighed.

Counts of 100 grains each for each slide were made subsequent to cruising the entire slide for determination of all the mineral types present. Neglecting mineral occurrences of low frequency, a count of 100 grains provides an ample degree of accuracy.

Clay Mineral Analysis. For clay mineral analysis approximately 10 grams of raw sample were placed in a beaker and treated with 36 per cent H_2O_2 until all activity ceased, which generally required several additions of the reagent. After oxidation, the samples were washed by decantation with distilled water until the suspension remained long enough to withdraw a minus 2 micron fraction, which in turn was used to sediment a glass slide (Grim, 1934). The oriented aggregate sample thus obtained was then

analyzed on a General Electric XRD-3 X-ray diffraction unit employing a goniometer speed of $2^\circ 2\theta$ per minute. Spectrometer traces were recorded on a logarithmic scale, and direct measurements of intensity (peak heights) were made from the trace after a suitable imaginary base line had been drawn.

Three slides of each sample were made—one being run in the untreated state, one treated with ethylene glycol, and one heated rapidly to 650°C and air quenched. In practice, the sample originally run in the untreated condition was subsequently ignited and rerun, thus eliminating any errors in later intensity comparison due to variations of thickness, etc., between different slides. All slides were permitted to come to equilibrium in an atmosphere of approximately 50 per cent humidity in order to sharpen up the peaks.

Oxidation of the samples was necessary because of the extreme diffuseness of the low angle peaks caused by the presence of organic material. Upon addition of hydrogen peroxide a rapid reaction took place, eventually giving way to a slow sustained reaction. If the sample were allowed to stand for a period of time it once again exhibited a substantial reaction with hydrogen peroxide, suggesting that bacteria (?) are present and are extremely difficult to destroy completely. Another interesting feature noted was that red clay reacted most violently and persistently in contrast to the olive-colored clay, contrary to the popular belief that red sediment indicates oxidizing conditions.

The treatment outlined above may have had some effect on the clay minerals, depending on their cation exchange properties.

Identification of Clay Mineral Components. For purposes of this report, routine identifications of illite, montmorillonite, chlorite, and kaolinite were made on the basis of the (001) sequence of reflections. Material which expanded to 17 AU upon treatment with ethylene glycol was designated as montmorillonite, 10 AU nonexpanding material was considered to be illite (detrital mica also falls into this category), 14 AU periodicity material withstanding ignition to 650°C was referred to as chlorite, and 7 AU periodicity material was assigned to kaolinite if it decomposed before 650°C .

Identification of Foraminifera. Samples were prepared for identification of the foraminifera by decanting the clay, drying, and, finally, floating off the air filled tests with carbon tetrachloride. This process was employed in preference to picking of the gross sample because of the rather wide size range of the tests, which prevented concentration by sieving. The separation proved efficient for these particular samples.

STATISTICAL PARAMETERS

For purposes of this study, the parameters employed are as defined by Folk and Ward (1957), which generally have been modified from Inman (1952). The phi (ϕ) scale of Krumbein (1934) is employed throughout to facilitate calculations and also as a matter of common usage; its relation to other measures is indicated in Table 3.

Most of the samples analyzed for this report contained clay in varying amounts, many in such large amounts that the 95 percentile, and not infrequently the 84 percentile, were beyond the practical limits of size analysis; therefore, the extrapolation method of Folk and Ward (1957, footnote p. 13) was employed. This practice consists of extrapolating lineally from the last measured point (approximately 10ϕ) to 100 per cent at 14ϕ , and plotting these extrapolated values on the cumulative curve. A sound basis for this practice may be found in electron microscope photographs of clays (Ref-

erence Clay Minerals, 1951, p. 129), which show a majority of clay flakes to have an average size of approximately 12ϕ .

TABLE 3
Relationship of grain size scales for sediments

Millimeters	Microns	Phi (ϕ)	Wentworth size class
1.00	-----	0.0	Coarse sand
0.84	-----	0.25	
0.71	-----	0.5	
0.59	-----	0.75	
0.50	500	1.0	
0.42	420	1.25	Medium sand
0.35	350	1.5	
0.30	300	1.75	
0.25	250	2.0	
0.210	210	2.25	
0.177	177	2.5	Fine sand
0.149	149	2.75	
0.125	125	3.0	
0.105	105	3.25	
0.088	88	3.5	
0.074	74	3.75	Very fine sand
0.0625	62.5	4.0	
0.053	53	4.25	
0.044	44	4.5	
0.037	37	4.75	
0.031	31	5.0	Medium silt
0.0156	15.6	6.0	
0.0078	7.8	7.0	
0.0039	3.9	8.0	
0.0020	2.0	9.0	
0.00098	0.98	10.0	Clay
0.00049	0.49	11.0	
0.00024	0.24	12.0	
0.00012	0.12	13.0	
0.00006	0.06	14.0	

Results and Discussion

TEXTURAL DISTRIBUTION AND GRAIN SIZE PROPERTIES

The neritic zone of marine deposition affords an excellent opportunity to study the interaction of source area and depositional environment as recorded in the texture of the sediments being deposited. Regardless of the original modality of material being supplied to this area by terrestrial agency it is believed that marine distributive forces tend to impart a modal distribution unique to the environment. This condition necessarily results from the features of hydraulic transport—more specifically, division of the load into a finer fraction carried in suspension and a coarser fraction moved by traction (“bed load” in fluvial terminology), the specific division being characteristic of the transporting energy of the waves at a particular point. Coarse material moving onshore by traction (essentially) creates a progression of single modes of decreasing medium size in the offshore direction. Super-imposed on this situation is the deposition of a fine mode from suspension with the net result being a bimodal sediment. Additional complexities in the final textural distribution of the sediments are introduced by intermediate means of transport, such as saltation, and sometimes by extreme fluctuations in both the intensity

and nature of the transporting agents. Source area will, of course, be representative of the aggregate modal frequency of the entire area of deposition, but its only local influence in the neritic zone will be to control the abundance of individual modes as they occur in the final depositional pattern. The analysis in terms of modal interaction set forth by Folk and Ward (1957) has largely remedied the previously speculative interpretation of sediments laid down under these conditions.

Distribution. A triangular classification employing sand, silt, and clay as poles provides a convenient means of indicating gross textures of the sediments analyzed for this report (Fig. 17). It may be noted that silt is present only in minor amounts with the exception of a small area near the mouth of the Brazos and in the very nearshore zone immediately to the west. The absence of material in the study area in the size range 6–10 ϕ is patent from a consideration of Fig. 18, which is a frequency curve plotted on the basis of all of the samples analyzed. This curve signifies that the source area is not supplying much medium and fine silt, and further presents the possibility that a universal deficiency of fine or medium silt may exist because the Brazos drains a large and diverse terrain. Future observations on this point certainly are indicated. Pure clays are absent from the distribution, 83 being the highest percentage obtained in the sample suite, but pure sands do occur on the beaches. The textures represented on the triangular diagram (Fig. 17) and the modal frequencies shown on Fig. 18 set up the limits within which the following discussion of sedimentary parameters must necessarily be bounded—a fact which should be constantly borne in mind.

A textural nomenclature employing the same sand-silt-clay triangular scheme (Folk, 1954, p. 349) is illustrated in Figure 19. The distribution of sediment types in the study area based on this nomenclature is shown in Figure 20. At first glance a certain amount of abrupt change between sediment types seems to prevail—this results from the gross nature of the classification and is not entirely indicative of the actual textural order attained by the sediments. Sand-silt-clay ratio is not refined enough to indicate the finer details of sedimentary distribution. In the discussion of the spatial aspects of the statistical parameters which follows later, this fact will be appreciated more fully.

An essentially uniform progression of sediment types extends from the well sorted unimodal fine sand and coarse silt of the beach to the predominantly clayey sediment at a depth of 50–60 feet just shoreward of the shoal area, at which point the trend re-

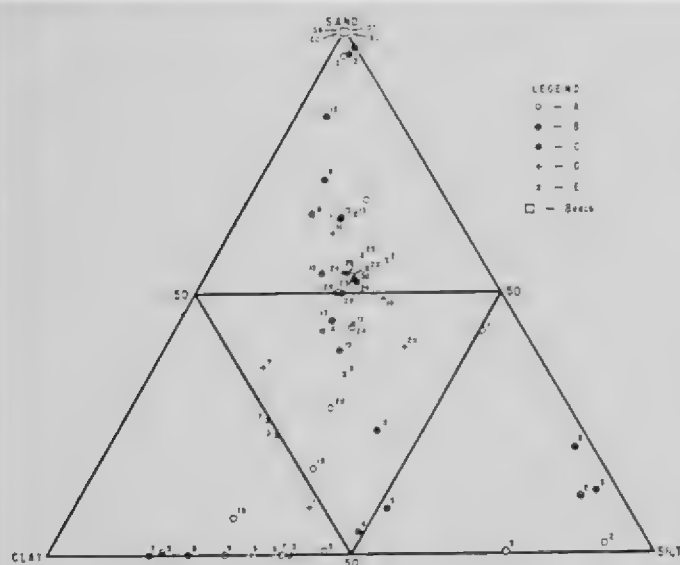


FIG. 17. Textural composition of the sediments.

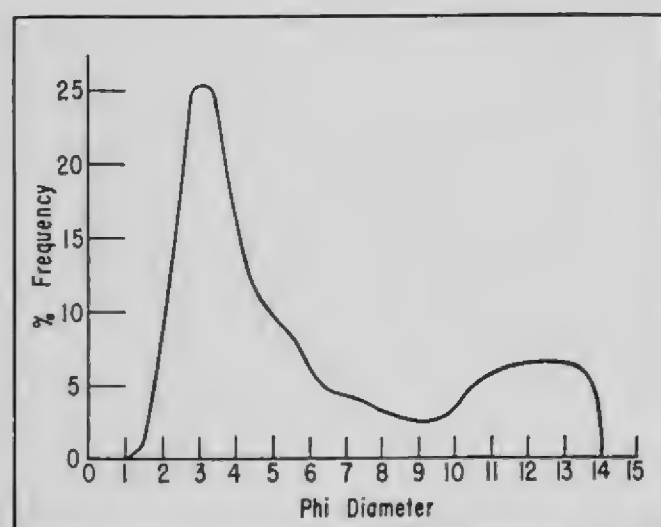


FIG. 18. Frequency distribution of size grades for all samples.

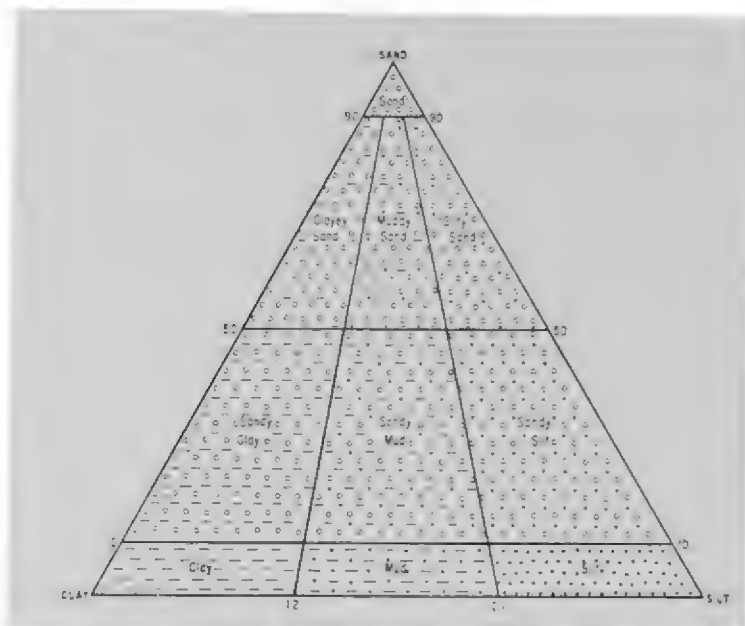


FIG. 19. Textural nomenclature triangle.
Adapted from Folk (1954).

verses and the sediment once again becomes coarser. The cause of this reversal is the presence of the submerged deltaic plain (the entire area seaward of the 60 foot depth contour) discussed at some length previously. Within the plain itself, a tongue of very fine sandy mud extends from the west in 70–90 feet of water into the main region of muddy very fine sand surrounding it.

The uniform progression of sediment types referred to above is the result of a decrease in modal size offshore from the beach. These modes comprise the “coarse” fraction referred to in the following sections and range from fine sand through coarse silt. The offshore topographic highs also supply a coarse mode in the sand size range. The “fine” mode referred to in following sections is a poorly sorted clay mode included between 10 and 14 ϕ . A band of silt adjacent to the mouth of the Brazos and extending west parallel to shore is the result of deposition of Brazos material, and represents a smooth transition from very fine sand through coarse silt to medium silt, at which size a definite break in properties occurs.

Distribution of the sediment about the modern delta follows a similar pattern to that described by Scruton (1955) and Shepard (1956) for the eastern Mississippi delta. Classical topset beds, represented by the subaerial portion of the delta surrounding the mouth of the Brazos, consist largely of fine material carried into lagoons by tides and storm waves (cf. previous section entitled Subaerial Delta). Borings from the delta (Odum, 1953a, p. 89–96) show coarse reworked material interlayered with fine material causing rather poor sorting. Sand, sandy silt, and silt zones grade seaward into an area of mud deposition, exhibiting a characteristic decrease in grain size into deeper water as well as in a lateral direction away from the delta proper. This sequence of sediment may be compared to the so-called “foreset” beds of the literature, but the dips of the beds in the study area are much less (1–2°). Slopes of this order are typical of most modern deltas (Shepard, 1956, p. 2615–2620).

A clay belt 7–8 miles offshore from the subaerial delta in 60 feet of water is related, as a general rule, to delta formation. According to Shepard (1956, p. 2559–2560) clay zones are related to river mouths in the Mississippi River delta: “Off all the passes there appears to be a consistent 50–70 per cent clay zone found within a few miles of the river mouths and forming a band around the distributaries.” Scruton (1955) referred to the same zones as “offshore clays.” Maximum deposition of clay from the suspension

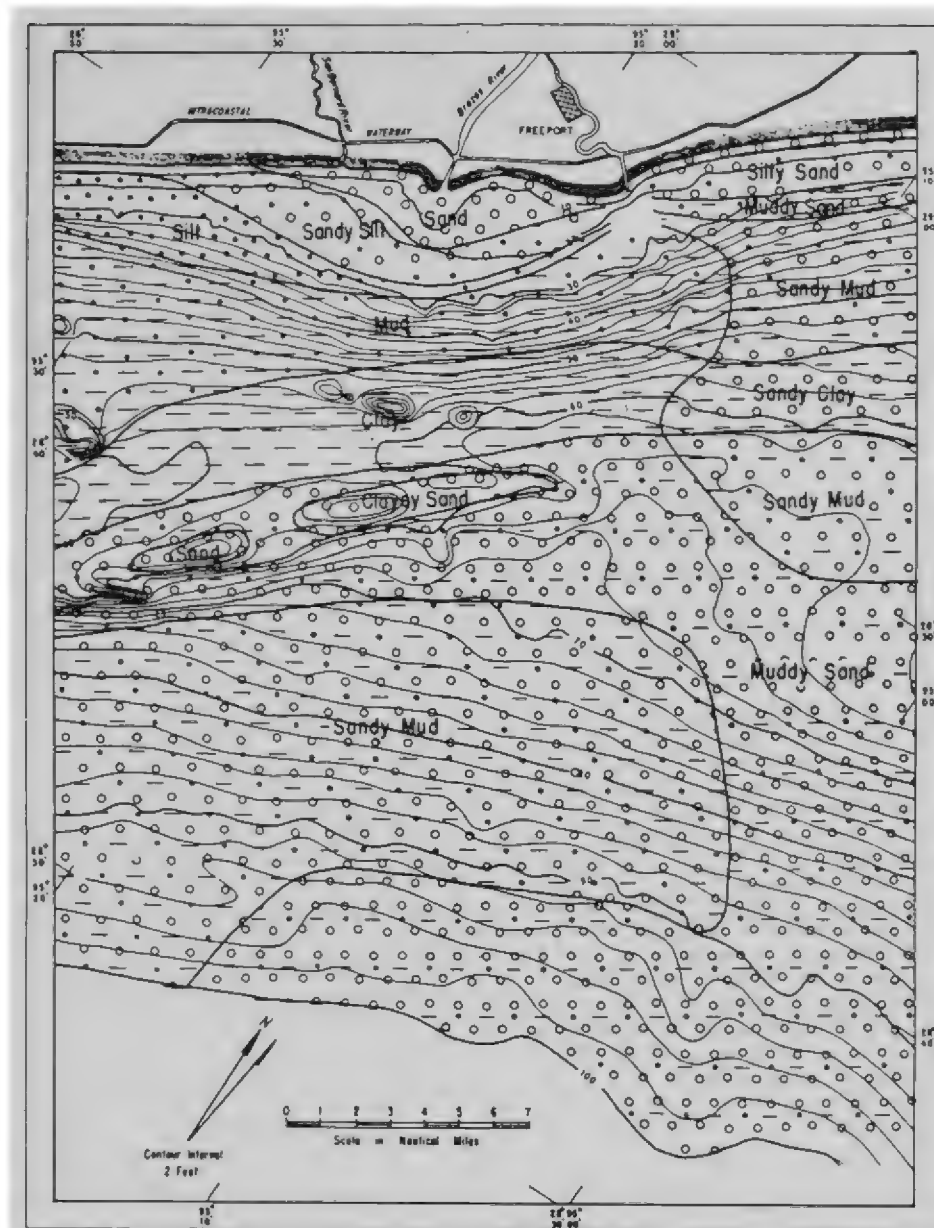


FIG. 20. Distribution of sediment types.

load of the river accounts for this clay accumulation. No relation exists between these clay belts and depth, their distribution with respect to the mouth of the river is more lateral than vertical.

Still farther seaward an abrupt coarsening to a zone of sand and muddy sand marginal to the clay belt occurs. Its fine material (fine silt and clay) is being deposited out of suspension from material supplied by the Brazos River, while the sand size material is probably derived from older sand of the submerged deltaic plain; that is, from the topographic highs caused by the outcrops of late Pleistocene sand. It is less likely, but nonetheless possible, that these outcrops are remnants of buried beach ridge, offshore bars, or possibly even reefs. A unique condition of double source area is thus imposed on the sediments of this region, and it was from this line of reasoning that the true relations presented by the contour map of kurtosis was revealed. What the map really indicates is the trimodal tendency of the sediment. The relative progression of mode size toward the offshore sand outcrops substantiates this interpretation. Sample A-10 (clay) has a subordinate sand mode at 3.25ϕ , A-11 (muddy sand) has a sand mode at 2.75ϕ , while on top of the high A-12 (sand) has a single mode at 2.70ϕ .

Relatively minor deposition of fine material over the large region seaward from the clay zone would constitute the "bottomset" beds needed to complete the classical pattern of deltaic deposition for the study area. As no cores were taken, direct evidence is

lacking that such a deposition of fine material is actually taking place. Paleontological and clay mineral composition data, however, indicate that deposition of clay is occurring in this area, at least in the region 10–20 miles offshore.

Fluctuations in the sediment distribution in the far offshore portion of the study area are the result of selective patterns of winnowing and sand deposition. Abnormal agents, e.g., hurricanes that operate in this region could account for the movement of large quantities of material, which would not subsequently be subject to modification by normal agents.

Properties. Consideration of the textural properties by means of their statistical parameters will be enhanced by noting the modal character of the shallow marine sediments as indicated by their size distributions.

Typical cumulative curves plotted on probability paper with their respective frequency curves are illustrated in Figure 21. Oyster cut is a very well sorted, nearly symmetrical, mesokurtic, unimodal sediment typical of the beach sand. Sample B-7 represents an almost unimodal clay distribution (100 per cent clay distributions are not present in the suite of samples from the study area). It is very poorly sorted and very negative-to negative-skewed, which would be anticipated from a predominant clay mode because of the physical properties of clay, and is mesokurtic despite its being coarsely skewed because of its very poor sorting. In D-7 a subequal mixture of the two modes results in a very poorly sorted, positive-skewed, very platykurtic size distribution. The clay mode in this sample is rather well developed.

The modal character of sediments in the study area may be reviewed in the following manner:

1. A "coarse" mode is represented by a well sorted mode in the fine sand to medium silt range, the particular size of the mode being determined by its position in the wave energy spectrum.
2. A "fine" mode consisting of a poorly sorted range of material in the clay size range. In a few sediments two modes are distinguishable within this range, resulting in trimodality of the particular sediments. A 100 per cent fine mode is not represented as such by any of the sediments in the study area.
3. These two principal modes may occur independently or may be mixed in any proportions.

Figures 22, 23, 24, 25, and 26 are profiles of the four grain size parameters plotted versus sample location (distance). For each traverse the depth profile is also indicated. These profiles should be referred to in the subsequent discussion.

Mean Size.—Values of mean size range between 2.3 and 10.5ϕ , clustering in the region of 5 to 7ϕ . This cluster of mean sizes approximately midway between the two main modes represents mixing of subequal portions of the modes (chiefly in the muddy sand and sandy mud zones offshore) and not an actual predominance of material of this particular size range in the sediment. Because of the scarcity of fine silt in this environment none of the samples analyzed had a primary mode in this region (as indicated by the sorting values—an interrelationship to be discussed in detail in a later section).

A significant feature of the mean size-slope relationship is the dependence of slope on the grain size of the sediment supplied to the slope. This is emphasized in Traverse B, where an abundance of silt size material has caused the slope to adjust in such a manner as to accommodate that particular grain size. Bascom (1951, p. 874) has also

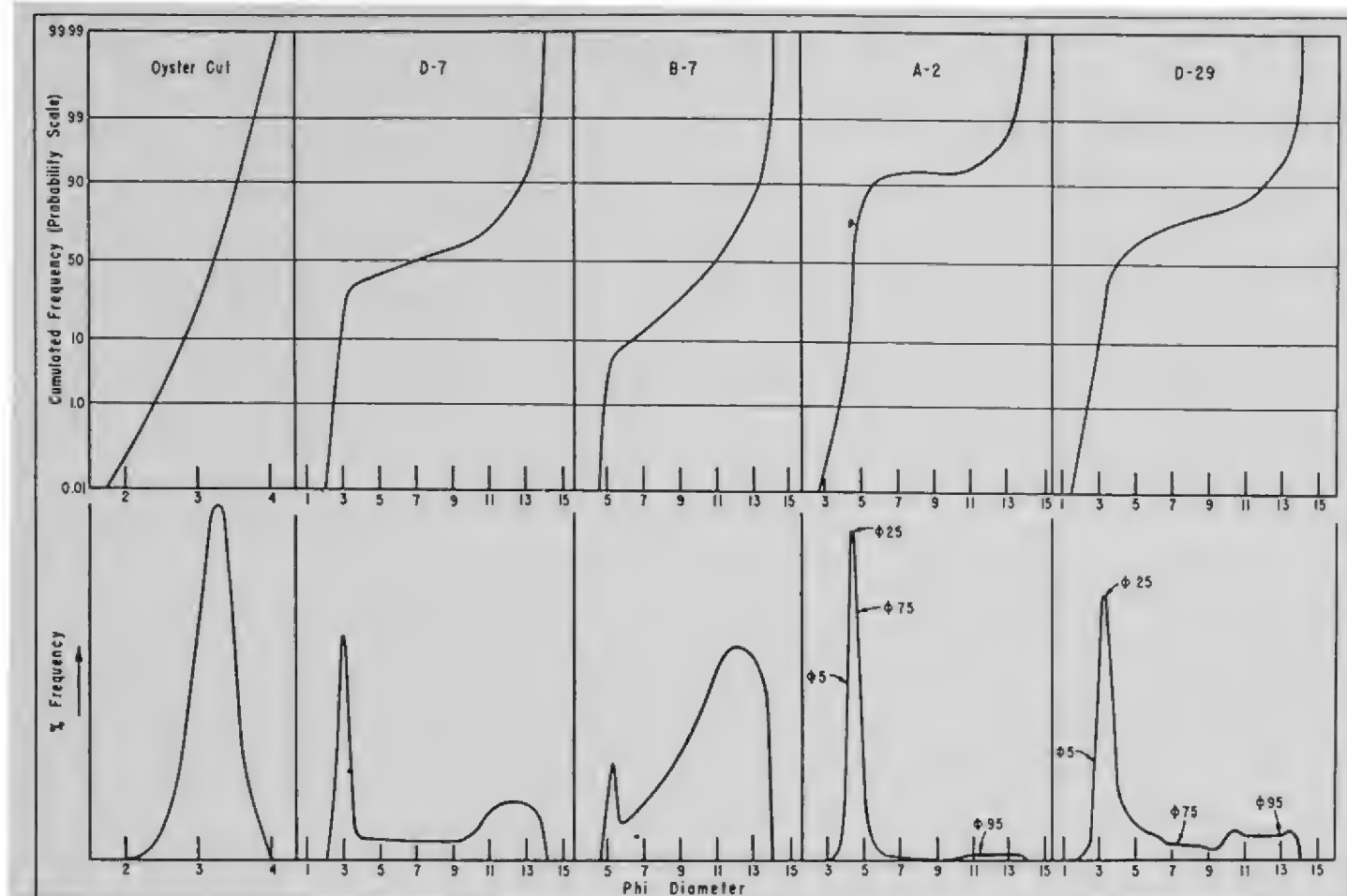


FIG. 21. Typical cumulative curves and their respective frequency distributions for sediment in the area of investigation.

noted this dependence of beach face slope on median diameter of the sand, and the long range effects of changing sand supply (or rather, changing grain size distribution) on the breach slope has been noted at Oceanside, California (Wiegel, Patrick, and Kimberley, 1954, p. 895).

A marked relationship of grain size with depth is at once apparent from an examination of the respective profiles. A bivariate plot of these parameters (Fig. 27), in which samples from the nearshore zone are designated by an x and those from the submerged deltaic plain by a circle, illustrates a number of interesting features. First, mean size and depth are obviously closely interrelated in the nearshore zone, decreasing regularly from an average of 2.8ϕ on the beach to over 10ϕ at a depth of 60 feet in the clay belt. Scatter around the indicated trend is the result of inequalities in grain size of material being supplied to the various localities. This conclusion naturally follows from the observation made in the preceding paragraph that slope is a function both of specific wave energy and mean size, and that, therefore, a particular locale will accommodate any relative spread of grain size being supplied to it by adjusting its slope. With this fact in mind it is not difficult to visualize the difficulty in attempting to carry a particular depth-mean size trend common to one area into another area where different local conditions of supply prevail. This weakness actually suggests a possible value of mean size-depth plots in respect to comparing various locales with regard to source area. If the respective trends were similar a common source would be indicated, but if the trends were quite different distinct source areas would be indicated (all the foregoing dependent on similar wave conditions).

Second, Figure 27 shows a break in steepness of the trend to occur at approximately 25–30 feet. The previously mentioned observation of Dietz and Menard (1951) to the

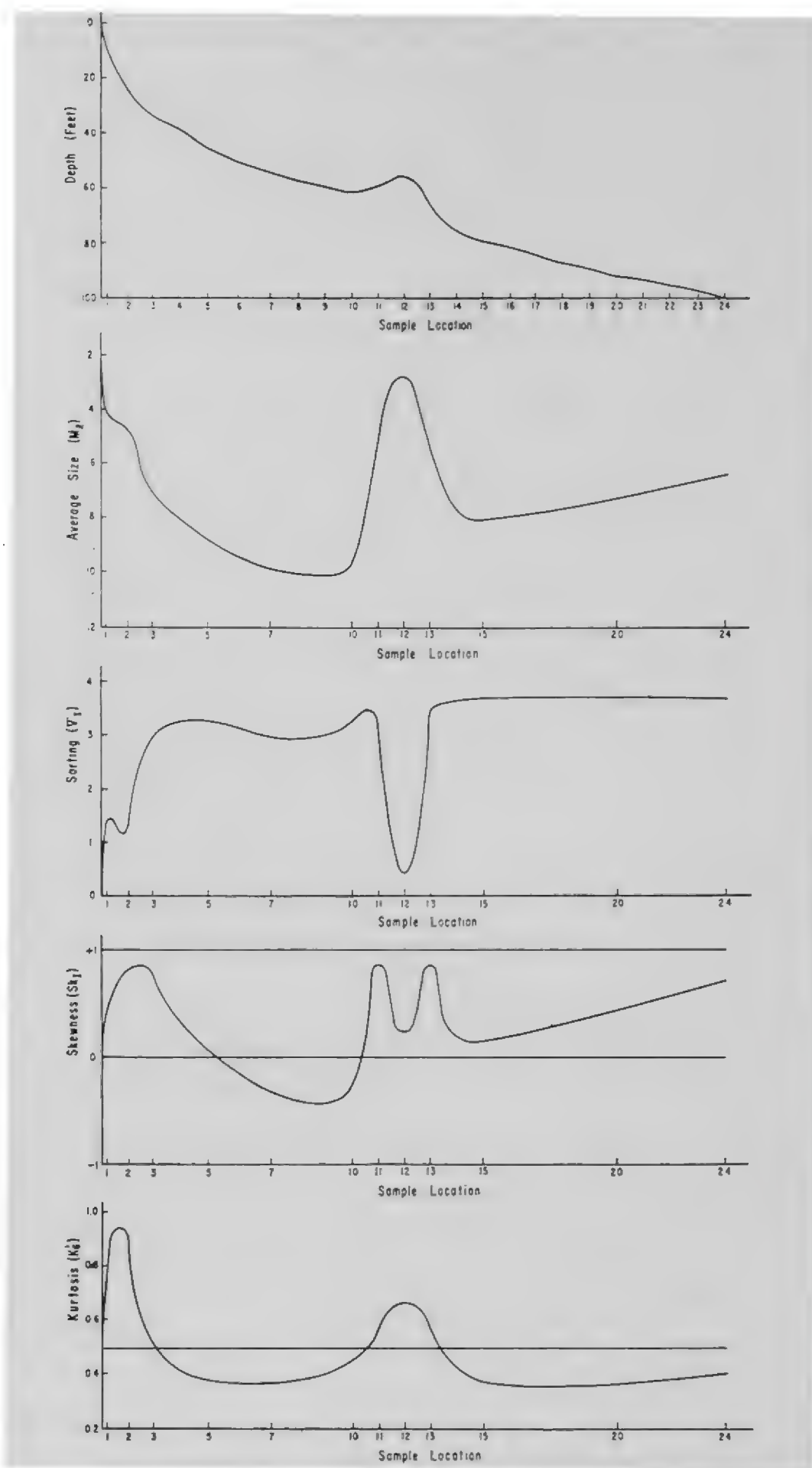


FIG. 22. Profiles of depth, mean size, sorting, skewness, and kurtosis for Traverse A.

effect that maximum erosion probably takes place at 25–30 feet also should be recalled. This feature might be a significant point to establish in analyzing ancient sediments with respect to determining direction to the paleoshoreline.

Third, the cluster of points about 6ϕ in depth below 60 feet indicate the bimodal mixture of subequal sand and mud in the region seaward of the 60-foot depth-contour, and

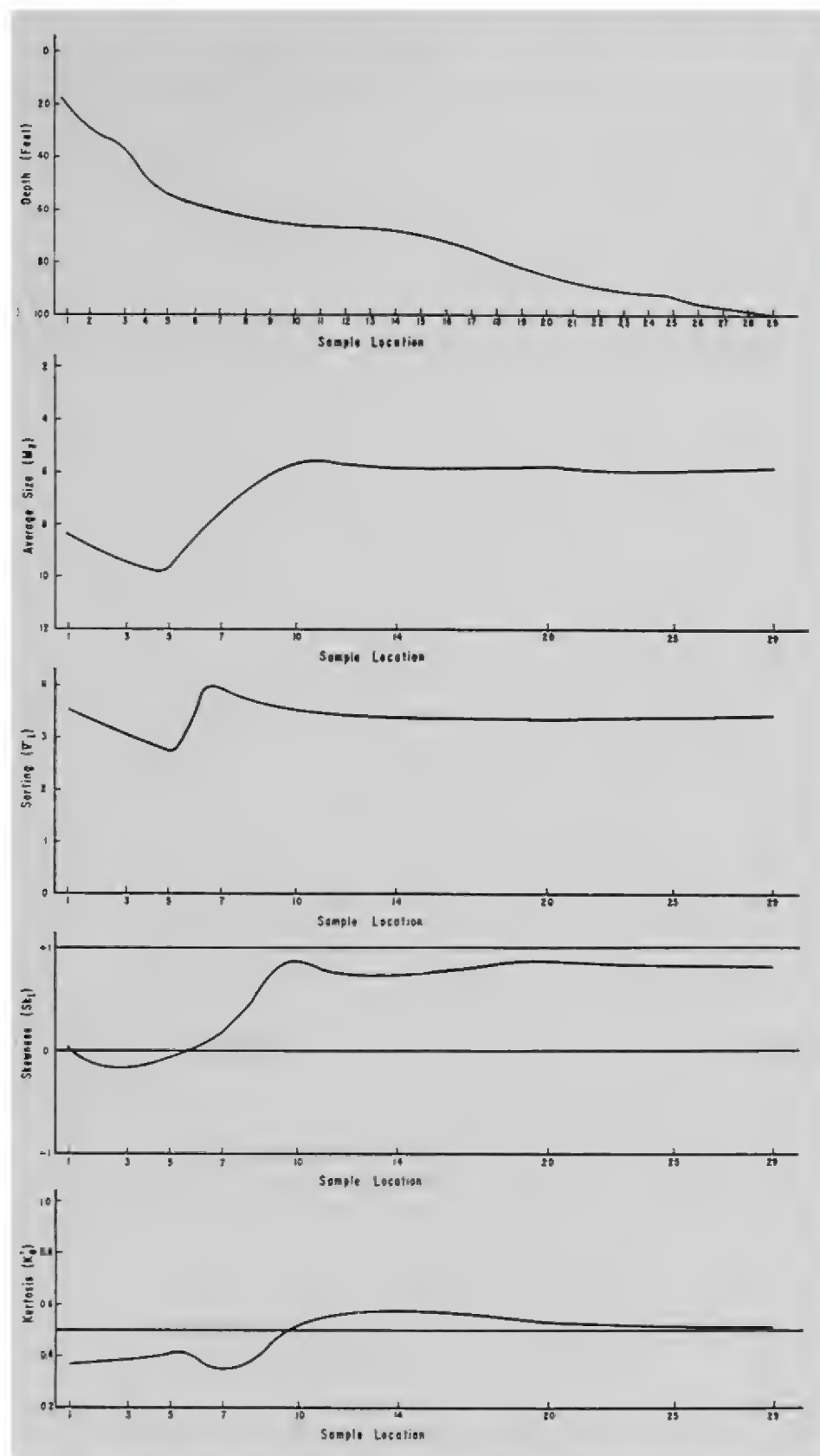


FIG. 23. Profiles of depth, mean size, sorting, skewness, and kurtosis for Traverse B.

a slight trend toward increased coarseness of the sediments offshore also seems to be indicated. This grouping of points serves both as evidence for the presence of an older deposit (the submerged deltaic plain) being reworked and for the deposition in this region of fine material from the Brazos with coarse material being brought in from another source.

Another interesting feature of this variance of mean size with depth is that in the close inshore zone of steepest slope and highest wave energy the sediment is unimodal (or at worst has a very predominant coarse mode), the modes decreasing in size offshore. The progression of coarse modes extends through the silt size range, but modes this fine are secondary, *i.e.*, they make up only a minor portion of the sediment. Note is once again made of the deficiency of this size material in the entire sample suite. Medium and fine

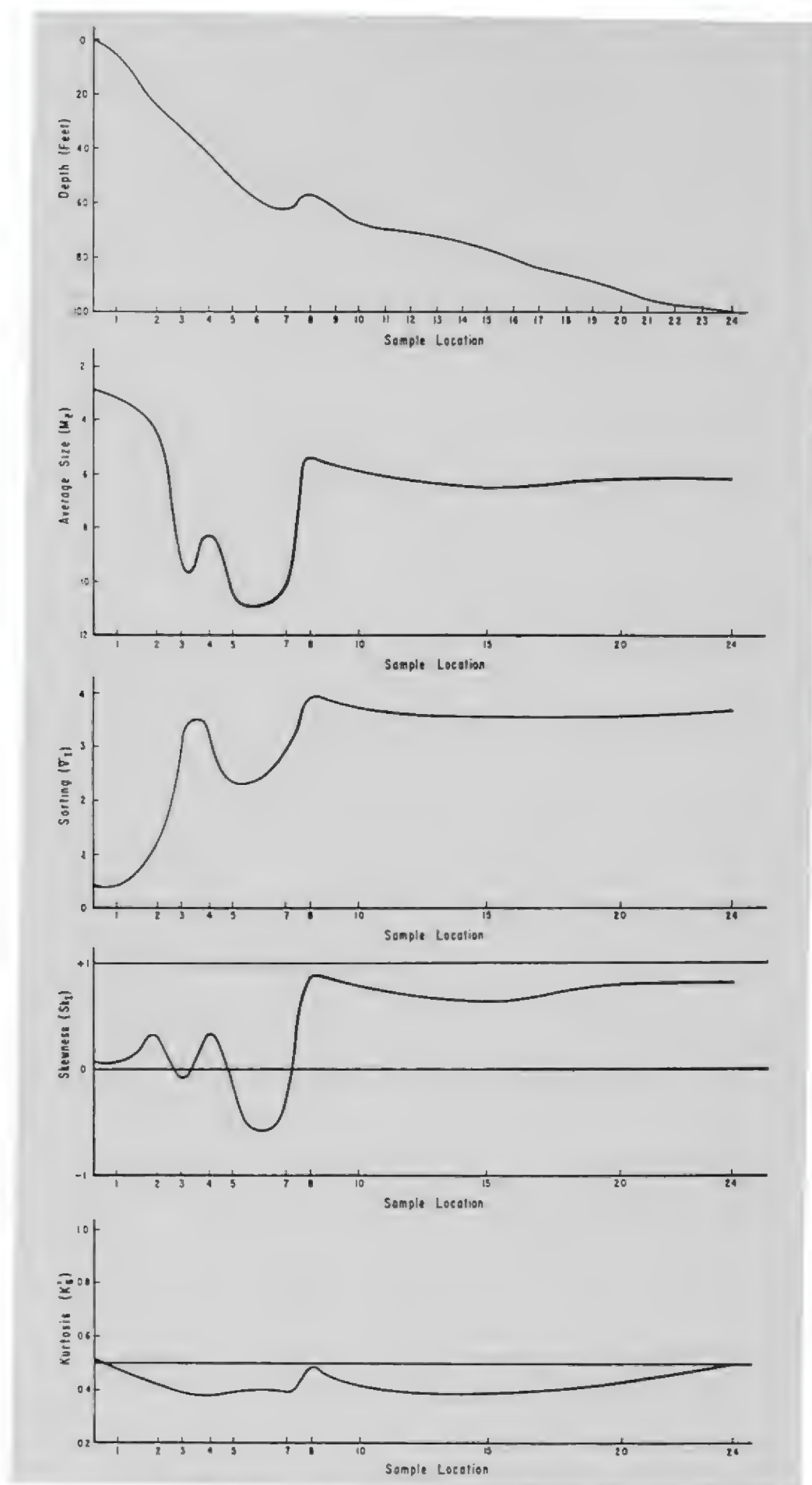


FIG. 24. Profiles of depth, mean size, sorting, skewness, and kurtosis for Traverse C.

silt approach the lower limits of applicability of the laws of hydraulics and a certain amount of diffuseness might therefore be anticipated in their size distribution for this reason. It may be concluded, then, that sorting in this region is segregating *specific* modes irrespective of any original modes the sediment may have inherited from the source area. The source area will, however, dictate the abundance or, for that matter, the

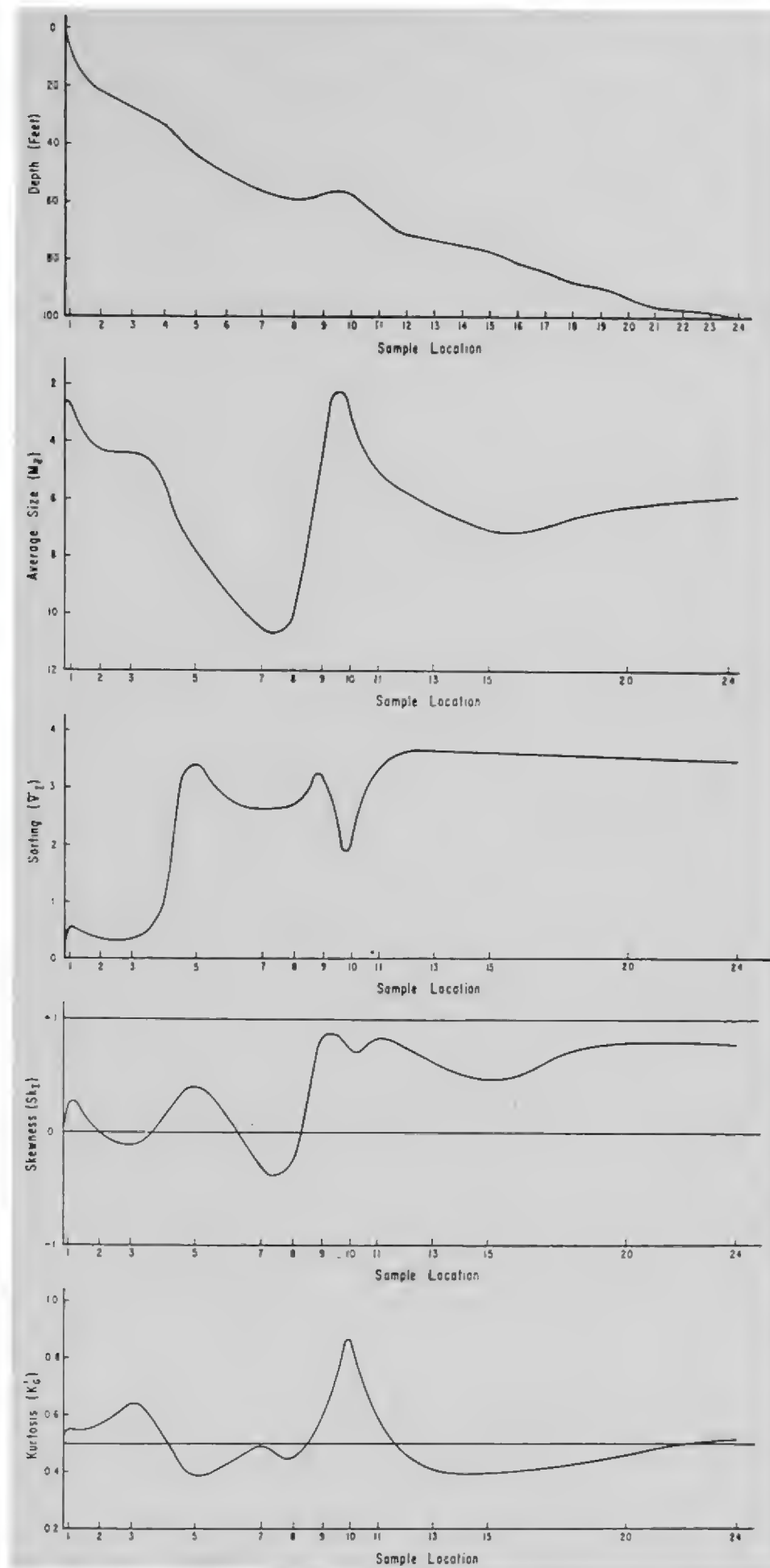


FIG. 25. Profiles of depth, mean size, sorting, skewness, and kurtosis for Traverse D.

occurrence of any particular mode. (Proof of this statement is the abovementioned progression of modes offshore.)

Topography is clearly reflected by mean size which outlines the sand outcrops and shows a consistent decrease offshore (to 60 feet); nevertheless, it is a moot question as to which parameter is independently and which dependently variable. The fact that

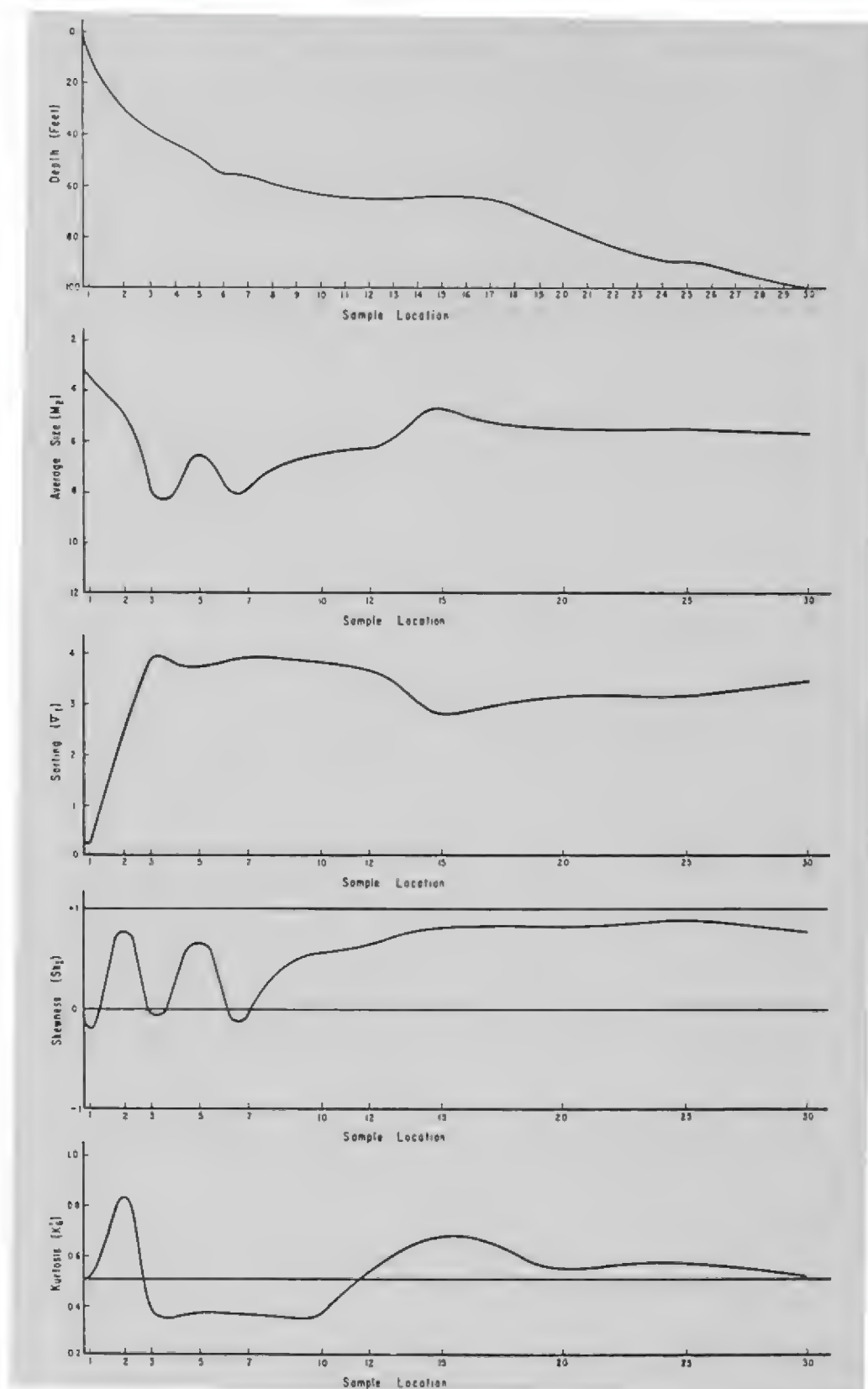


FIG. 26. Profiles of depth, mean size, sorting, skewness, and kurtosis for Traverse E.

the elevations occur at approximately 60 feet, which is the depth generally taken to be the lower limit of effective wave action, is probably significant. In Traverse E only a slight increase in elevation in the vicinity of stations 13-18 is related to a marked increase in mean size.

Standard Deviation.—The relationship between sorting and mean size mentioned above also apply to the plot of standard deviation. Best sorting occurs in the beach and nearshore region, with relatively good sorting on the topographic highs, particularly at station A-12. Values of standard deviation ranged from 0.25ϕ at E-1 to 3.96ϕ at D-7.

A general trend toward improved sorting values (relative to the adjacent sorting values) in the vicinity of the clay belt is caused by the predominance in this region of the nearly pure clay mode (cf. particularly Traverse A (Fig. 22) and Traverse B

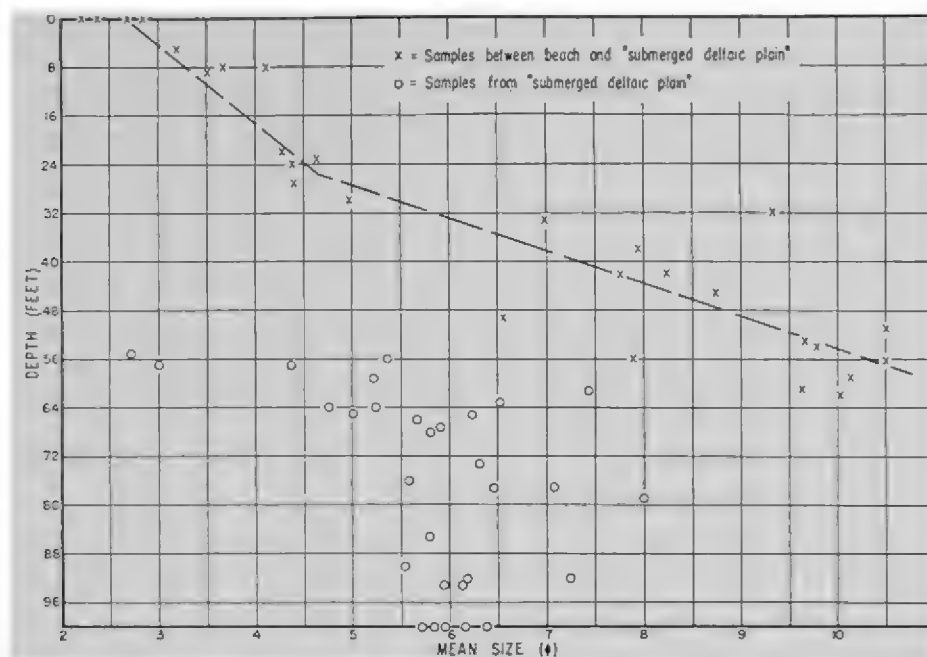


FIG. 27. Scatterplot of mean size and depth.

(Fig. 23). Poorer sorting (higher standard deviation values) exists in the intermediate area between the beach and the clay zone as a result of mixing of the two main modes.

Proof of the statement made by Ippen and Eagleson (1955, p. 77–88) concerning the mixing of various size grades at any break in bottom slope is obtained by comparing the profiles of depth and standard deviation. At each change in slope on the depth profile a corresponding abrupt increase in values of standard deviation occurs, indicating very poor sorting due to a more or less heterogeneous mixture of size grades.

High values of standard deviation (poor sorting) evident in the region of the submerged deltaic plain indicate that this area is functioning passively in respect to sediment transport. A predominance of mean size values in the range of a rather coarse mode would be expected to occur with a lower range of standard deviation value than actually are present. The conclusion can be drawn, then, that in depths of water greater than approximately 60 feet (the minimum depth of water over the region of the deltaic plain) fine material derived from areas onshore of the 60-foot depth-contour is quietly being deposited in this deeper water. Turbulence caused by waves is insufficient at these depths to lift the bottom sediment and place it in motion or even to keep the suspended load arriving in this region from settling out. Poor sorting in depths greater than 60 feet may be interpreted as placing a lower limit on the effectiveness of sorting action in the neritic environment. Beyond this point the sediments can be expected to become progressively finer grained and sorting becomes a function entirely of the depositing medium—no redistribution occurring after the suspended material has been deposited.

Skewness.—Skewness is a very effective indicator of the modal nature of sediment. Well developed unimodal distributions are symmetrical, as are equal mixtures of two modes, while mixtures of two modes in very subequal amounts cause extreme values of skewness. Depending upon which mode is dominant, coarse or fine, skewness values will be positive or negative, respectively. Traverse A (Fig. 22) is an excellent example of skewness as a function of bimodality. The well developed unimodal beach sample exhibits near symmetry, but as distance offshore increases the sediment becomes progressively finer and finer (more positively) skewed to a point where the addition of the finer mode is in a large enough quantity to effect the spread of the central portion of the curve as well as the tails, and skewness values decrease. When the modes are mixed

in equal amounts (in the region of sample A-5) a symmetrical condition arises and in the region farther offshore skewness becomes progressively more negative. A return to symmetrical values in the proximity of A-10 indicates mixing of the two modes in equal amounts once again, rather than a return to a perfectly unimodal sediment, as a pure clay (fine mode) is not present. The bulk of the zone offshore from the 60-foot depth-contour has strong positive skewness because of the dominance of the coarser mode.

For the study area skewness ranged from -0.35 to $+0.88$, with a predominance of positive-skewed values. The significance of the fact that a majority of the samples were positive-skewed is that the sample suite nearshore represents a shallow neritic environment with the coarse mode still dominant. If sampling had been carried out to greater depths, where the clay (fine) mode predominated, negative-skewed values would be the order of the day. With no great stretch of the imagination one can envision a frequency plot of skewness values serving to indicate direction from the shoreline—an increase in positive-skewness values showing progressive nearness to the shoreline, while an increase in negative-skewness values would indicate an offshore direction.

Sharp peaks of positive-skewness effectively mark the edges of the topographic highs.

Kurtosis.—Like skewness, kurtosis is an effective indicator of the modal relationships of a sediment.

Values of kurtosis range from 0.53 to 9.37 for the study area, inclusive of a fairly uniform spread of platykurtic and leptokurtic values.

The uniform progression of modal additions noted on Traverse A (Fig. 22) in the previous discussion of skewness is also indicated in an obvious fashion by the profile of kurtosis values. The nearly unimodal (but not perfectly unimodal) samples are excessively peaked (leptokurtic), while the intermediate samples representing subequal proportions of the two modes become progressively mesokurtic, and those sediments with equal amounts of the modes are deficiently peaked (platykurtic).

The non-normal nature of kurtosis is illustrated in Figure 21. From the frequency curve it will be noted that in sample A-2 the addition of a small proportion of the fine mode ($> 15\text{--}20\%$) causes extreme leptokurtosis. The addition of slightly more of the fine mode ($20\text{--}30\%$) produces mesokurtosis as indicated in sample D-29. Subequal or equal amounts ($30\text{--}70\%$) of both of the modes cause platykurtosis, as on Sample D-7. Thus, from the range of relative values of kurtosis for a given sample suite one might predict the relative proportions of the modes contained in a particular sample.

Traverse C (Fig. 24) presents an interesting situation. The kurtosis and depth profiles are almost identical. The latter feature points up the high degree of interrelation between not only kurtosis but all of the statistical parameters with each other and with their environment as represented by the depth profile. The fact that all of the samples in this traverse, which is off the mouth of the Brazos, are deficiently peaked indicates that the river is depositing coarse material faster than marine forces can redistribute it. The progressive sorting action of the neritic environment does not have the opportunity to rework the sediment, with the net result being a poorly sorted sediment with a wide separation of modes occurring in subequal to equal amounts.

Further detailed discussions of the four statistical parameters follow in the next sections.

SPATIAL RELATIONSHIPS OF GRAIN SIZE PROPERTIES

Having presented the significance of the several grain size parameters in profile, we may now proceed to the spatial aspects.

Recent papers on spatial distributions are almost entirely lacking with a few notable exceptions (Krumbein and Aberdeen, 1937; Inman and Chamberlain, 1955; Trask, 1955; and Shepard, 1956). The writer knows of no papers in which skewness and kurtosis have been individually treated.

Mean Size. Contours of mean size (Fig. 28) conform with topographic contours offshore to the limit of effective sorting by wave action. Beyond this point the alongshore configuration is hardly patent, the change indicating that a different set of agents predominate. The geologic history of the study area beyond the 60-foot depth-contour, as recorded in sedimentary properties retained from an earlier period of deposition, may explain the present lack of alongshore conformity. If normal nearshore agents were operative in this depth of water (> 60 feet) an inherited configuration might be destroyed and subsequently replaced by one more compatible. Storm waves may be in large part responsible for the grain size distribution in this deeper zone inasmuch as normal wave action cannot operate at these depths to erase the effects of the occasional storm waves.

Another agent that may influence the mean size pattern in deep water is bottom current for which we do not yet know the mechanics. The transport of heavy minerals from the Mississippi River out to a depth of at least 200 feet, mentioned by Shepard (1956, p. 2598), suggests that deep-water bottom currents may be rather competent. Also, the presence of the submerged deltaic plain must partly (or maybe dominantly) influence the distribution of mean size in the portion of the study area that it occupies.

Topographic highs are precisely reflected by mean size, as would be anticipated. The closed 10 ϕ contour approximately 7–8 miles offshore accurately delineates the relationship of the so-called "clay belt" to the mouth of the Brazos River.

Standard Deviation. Sorting and mean size are so interdependent that the trends of mean size (Fig. 28) are also reflected in contours of standard deviation (Fig. 29). Progressively poorer sorting occurs offshore to a maximum midway between the locations of the two main modes, the beach and the clay belt respectively. The poor sorting of the clay mode is so dominant that the bimodality of the sediments is partly obscured, indicating the necessity of employing jointly all of the statistical parameters in order to accurately interpret the sediment.

Once again, the topographic highs are clearly outlined. A wedge of improved sorting extending into the area from the northeast illustrates the effectiveness of the winnowing process on even very minor elevations (in the range of 2–4 feet of relief). Contours of mean size did not reflect this particular topographic anomaly.

The existence of relatively poorer sorting closer to shore in the northeastern portion of the study area probably is due to a local reduction in wave energy caused by the minor elevation offshore from the anomalous zone.

Skewness. Contours of skewness (Fig. 30) effectively illustrate the modal nature of the sediment in an orientation parallel to shore. The fine mode, which was almost obscured on the map of standard deviation, is clearly indicated by negative-skewness values. Also, the modal characteristics of the sediment onshore from the 60-foot depth-

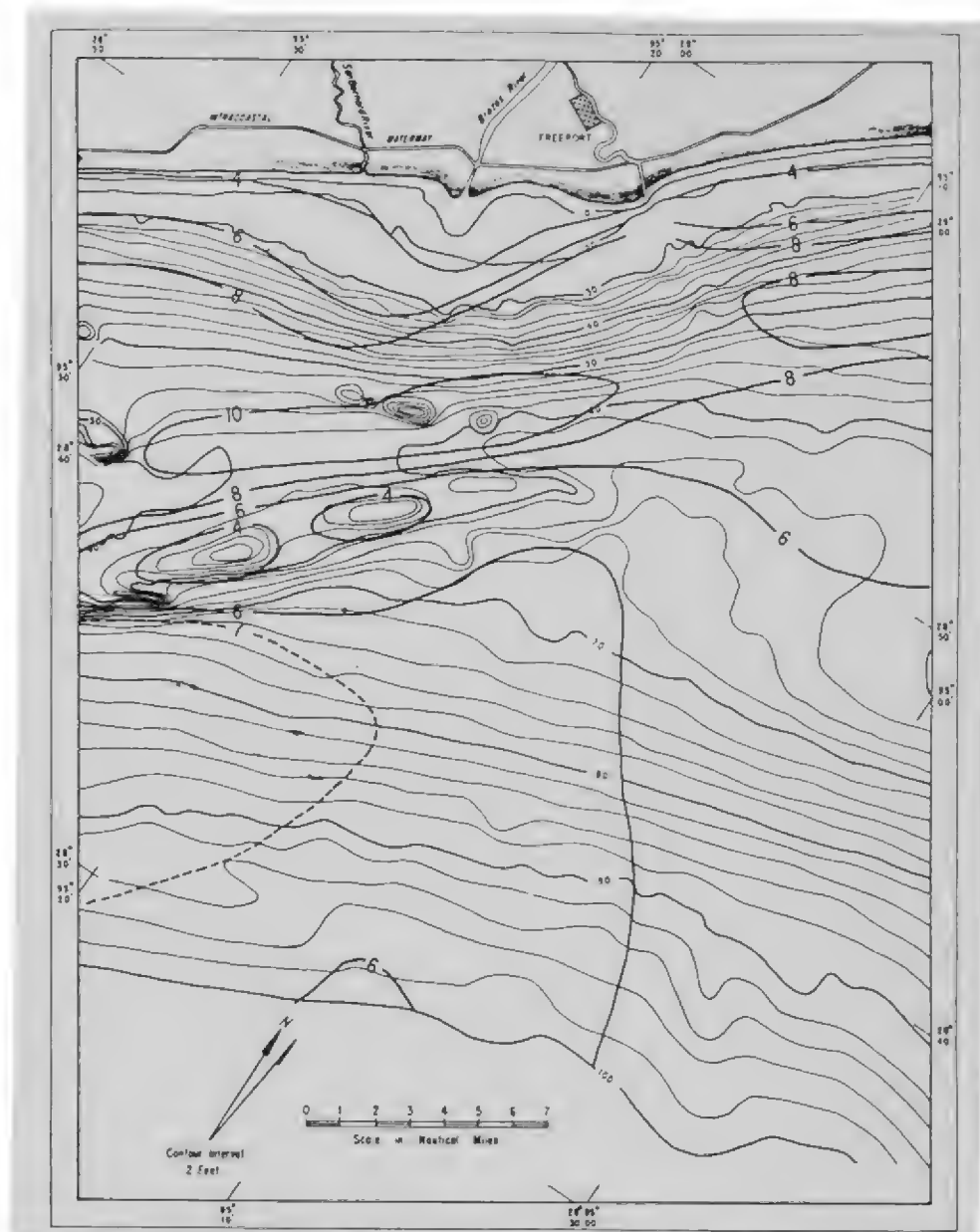


FIG. 28. Contour map of mean size.

contour, which were completely obscured by poor sorting, are shown in detail by the skewness contours.

Topographic features are reflected only to a very minor extent (in comparison to mean size and sorting) by skewness values, indicating again that the various parameters must be used in conjunction with one another. The change in grain size represented by the 7ϕ contour on the mean size map is also reflected by a trend toward more symmetrical skewness relative to the adjacent sediment.

Kurtosis. An entirely different pattern is presented by the map of kurtosis (Fig. 31), showing more similarity with the plot of standard deviation than with any of the other parameters. At first glance the modal character of the sediment as defined by kurtosis is quite different from that as defined by skewness. The apparent conflict is due to the extreme sensitivity of the kurtosis measure. Although, as has been mentioned previously, the pure clay mode is not present in the sample suite of the study area, its presence is clearly indicated by the platykurtic area contained within the $0.400 K'_G$ contours.

Specifically proceeding seaward from the beach, where mesokurtic values signify a well developed unimodal sediment, extreme leptokurtosis is encountered, representing additions of a secondary clay mode in amounts less than 15–20 per cent. Farther offshore kurtosis values decrease, indicating progressively larger additions of the fine mode until platykurtic values occur, signifying approximately subequal amounts of the two

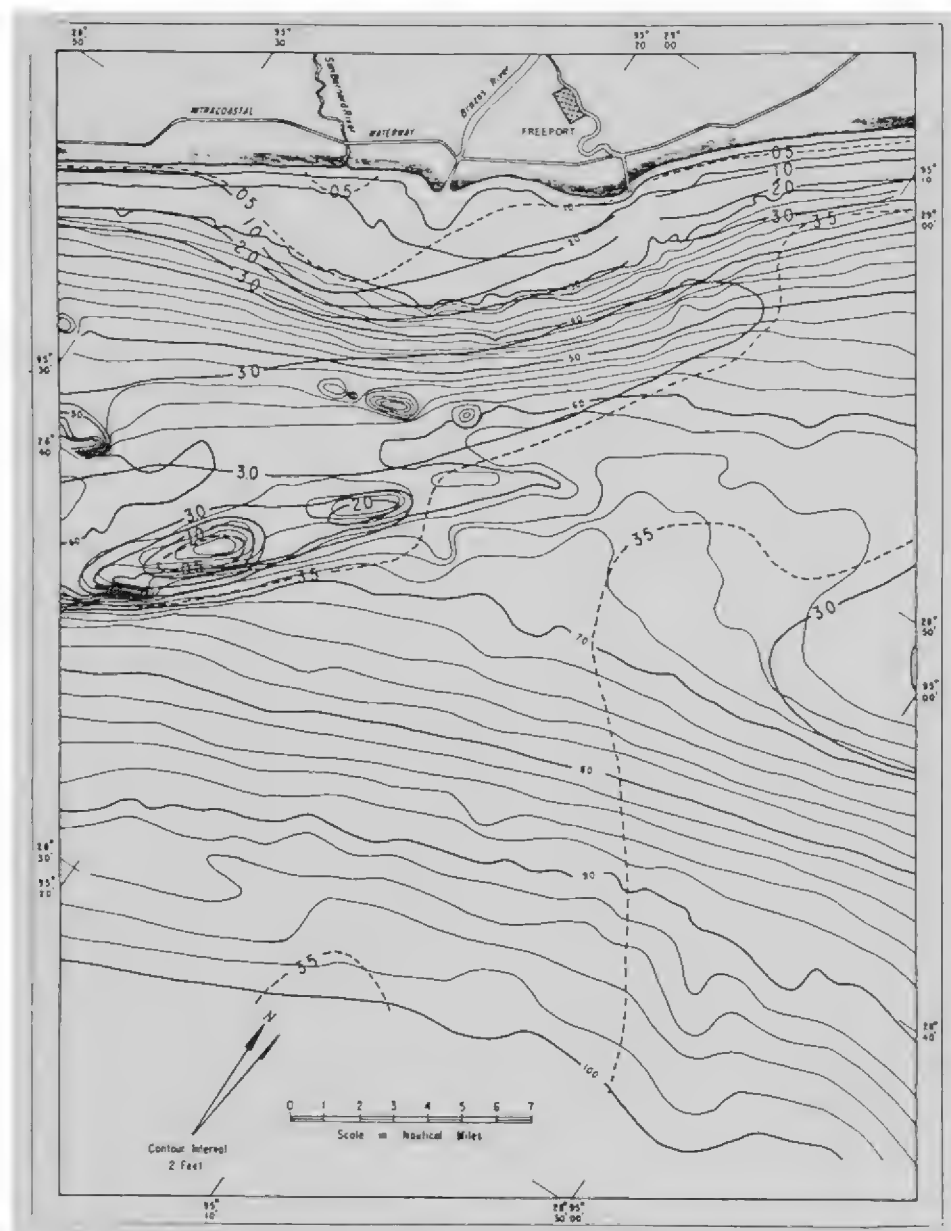


FIG. 29. Contour map of standard deviation (sorting).

modes. Still farther offshore an exactly reversed condition prevails until on top of the topographic high an essentially pure coarse mode is once again encountered.

The closest approach to the pure clay mode is shown by the small $0.475 K'_G$ contour, indicating an approximate 70 per cent addition of the fine mode. Clay is actually present in the amount of 83 per cent, the discrepancy being introduced by the occurrence of a third mode in the range of $7-8\phi$. These two modes generally are not distinguishable and show up as one poorly sorted fine mode. The fact that kurtosis indicated this trimodality was not immediately realized, as was indicated in the discussion of the distribution of sediment types (p. ...).

Three areas of coarse modes are shown on the map; the beach, the prominently elevated region, and the very minor elevation in the east central portion of the study area. The closed $0.400 K'_G$ contour off Freeport Harbor represents a remnant of the Old Brazos River delta in the nature of a clay belt, which always occurs off the mouths of rivers.

Kurtosis and skewness together can yield a complete picture of the modal characteristics of sediment, and an increased usage of kurtosis is certainly indicated.

INTERRELATIONSHIP OF GRAIN SIZE PARAMETERS

A detailed bivariate analysis of the various grain size parameters is useful in determining the geologic significance of the individual environment. Frequent reference to

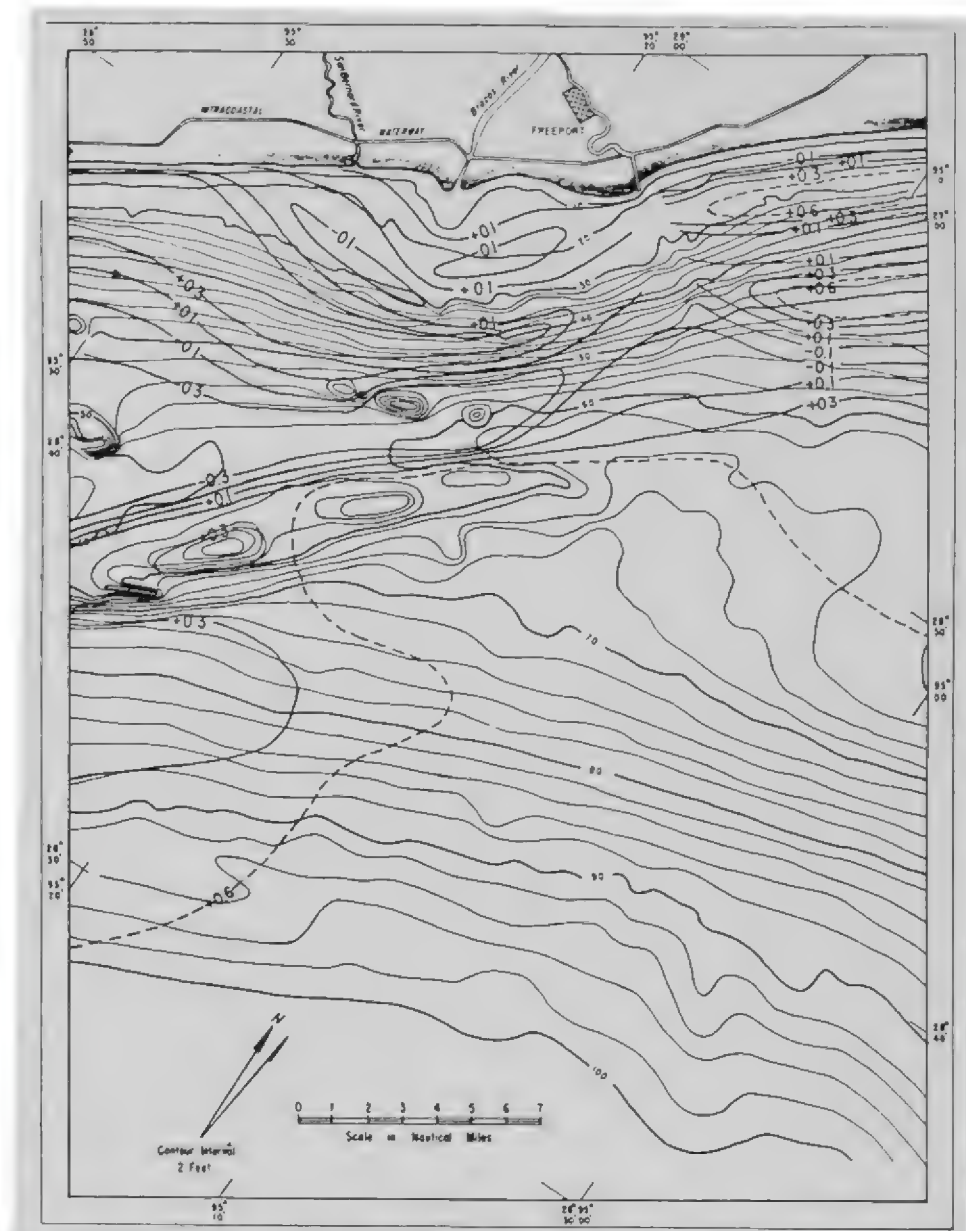


FIG. 30. Contour map of skewness.

the contour maps presented in the preceding section will aid materially in visualizing the interrelationships to be indicated by means of the following scatterplots.

MEAN SIZE VERSUS STANDARD DEVIATION

The relationship of mean size and standard deviation is the best known and most thoroughly studied of all of the grain-size parameters. For the limited range of sizes available in the study area, the scatterplot (Fig. 32) exhibits a marked trend which is related to the particular modal characteristics of the sediment.

Beach and very nearshore samples are very well sorted to well sorted and cover a relatively large range of mean size from 2.3 to 3.5 ϕ . These sediments are the product of the highest sorting attainable in the neritic environment—a fact which accounts for the extended size spread. The efficacy of sorting in this zone is such that regardless of the size of the material supplied, good sorting is imposed. Support of this statement is to be found in the previously mentioned dependence of beach slope to median size. A similar conclusion is drawn by Folk and Ward (1957, p. 18–19) in a theoretical consideration of the bivariate nature of mean size and standard deviation. These beach and very nearshore sediments represent the well developed coarse modes (very fine sands or coarse silts) which are mixed in decreasing proportions with the not so well developed fine (clay) mode to produce the poorly sorted sediment of mean size intermediate between the two main modes. Modal mixtures of roughly equal proportions yield the

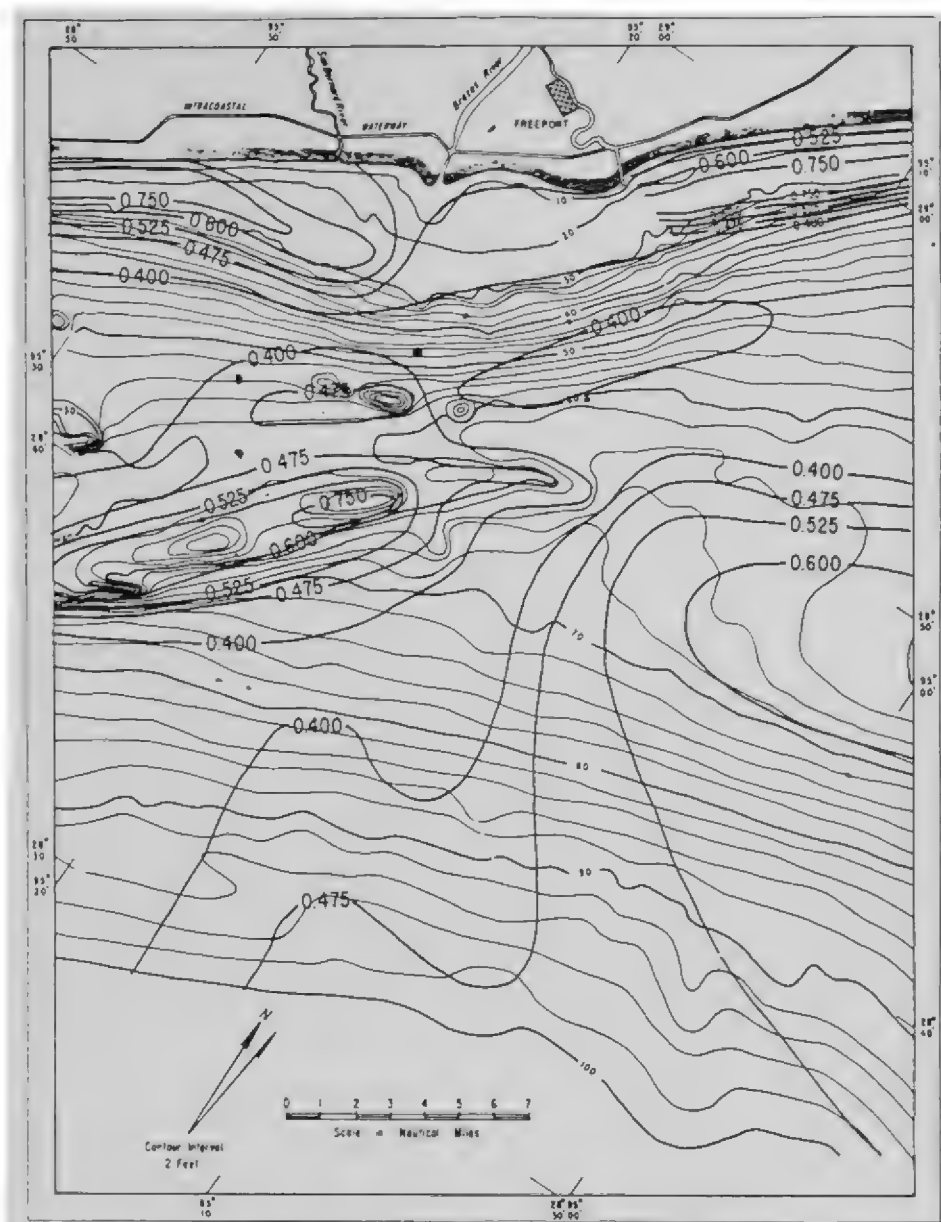


FIG. 31. Contour map of kurtosis.

poorest sorting, as they possess well developed extremes and a poorly developed central portion (cf. Fig. 21, Sample D-7).

Generally poor sorting prevalent in the finer grades (clay size range) is a result of the essentially uniform reaction of these sizes to hydraulic action in the form of traction movement or creep. Nevertheless, as suggested by Inman (1949, p. 61-63), when this material is suspended it is sorted by the large differences in settling velocities of the various grain sizes. A trend toward improved sorting is definitely shown on Figure 32 for samples with mean size finer than 8ϕ . Although no pure clay was present in the sample suite, it is assumed that the standard deviation of even a relatively pure clay would not qualify it to be placed in much more than a poorly sorted classification because it is colloidal and probably is composed of a variety of minerals, and consequently its physical properties are variable.

Assuming the indicated trend to be sinusoidal, the equation of its curve can be determined as a matter of interest. Examination of Figure 32 indicates that for an average maximum standard deviation of $3.9 \overline{V}_I$, average mean size is 7.0ϕ ; and that for an average minimum standard deviation of $0.3 \overline{V}_I$, average mean size is 3.0ϕ . Employing these values and applying the general formula for a sine function

$$y = a \sin \theta + b,$$

the specific relation

$$\overline{V}_I = 1.8 \sin 45^\circ (M_z - 5\phi) + 2.1 \overline{V}_I$$

is established. The dashed line of Figure 32 is the curve of this equation.

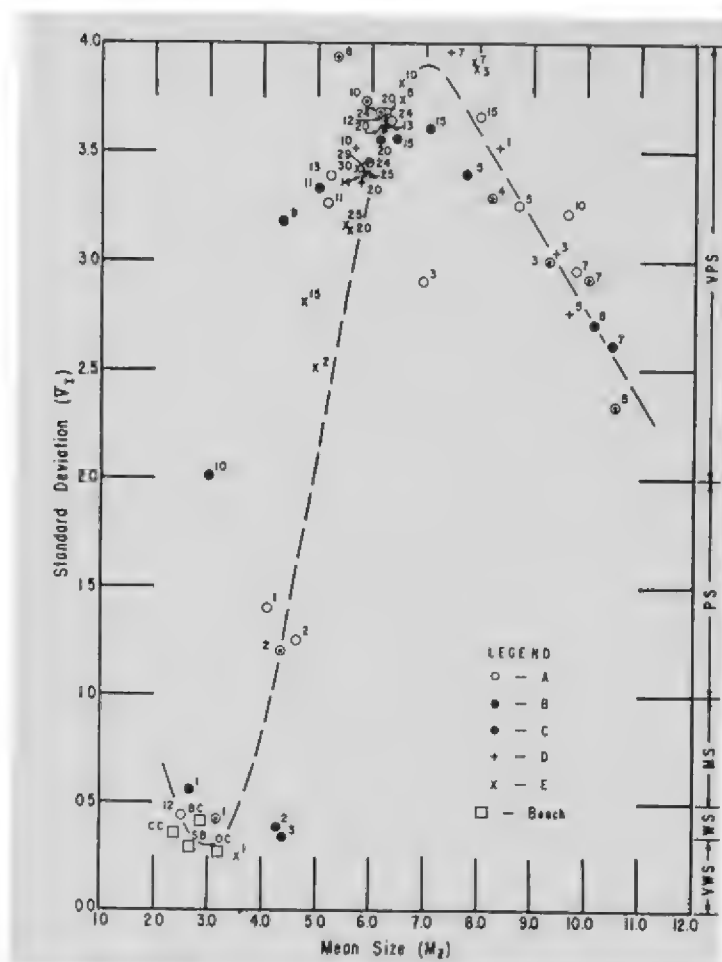


FIG. 32. Scatterplot of mean size and standard deviation.

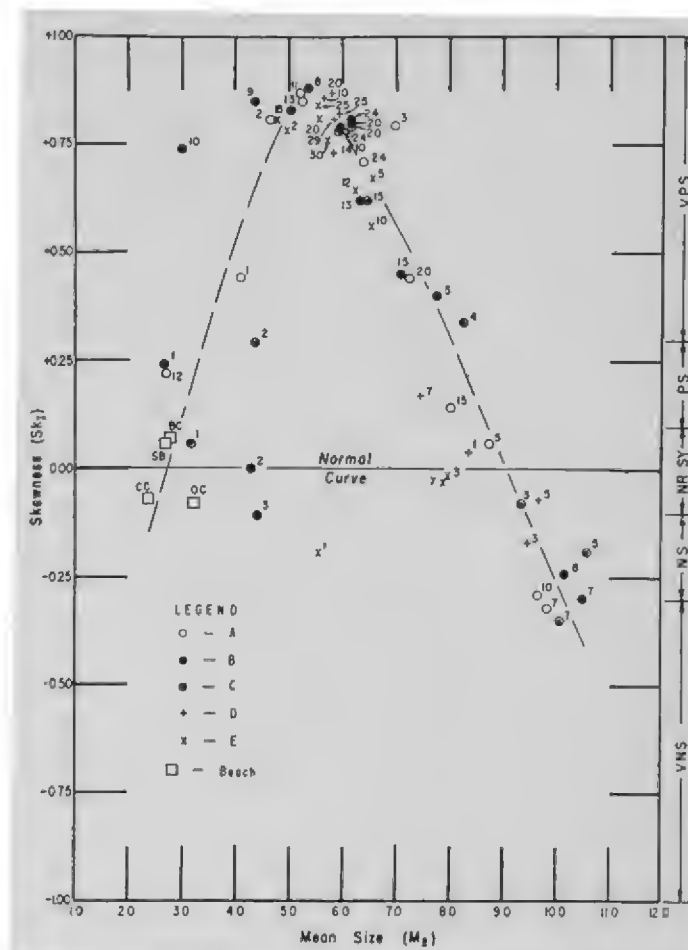


FIG. 33. Scatterplot of mean size and skewness.

A continuation of this sinusoidal trend into coarser sizes can be observed in grain size studies made by Blatt (1958, p. 74) and Folk and Ward (1957, p. 17). Blatt's curve, representing beach sand and gravel, directly adjoins the curve of this report, while that of Folk and Ward, compiled from analyses of river sand and gravel, has a similar configuration but is displaced upward into poorer sorting values. These three studies are directly comparable as they all employed the same statistical measures, namely, those of Folk and Ward (1957).

Both from this study and by comparison with the above mentioned work it may be concluded:

1. A distinctive sinusoidal relationship exists between mean size and standard deviation which is an accurate measure of the modality of sediments and an effective indicator of environment.
2. The relative position of the curve with respect to sorting distinguishes the littoral environment from the fluvial environment.

Mean Size versus Skewness. A sinusoidal trend is apparent in the scatterplot (Fig. 33) of mean size and skewness, but is displaced toward the coarser sizes in comparison to the mean size-standard deviation plot. The high degree of scatter in the near symmetrical zone is caused by the independent nature imparted to mean size by the efficacy of the very nearshore environment. Predominance of extremely positive-skewed samples is a result of sampling only nearshore sediment, with the trend toward negative-skewed sediment farther offshore from the 100-foot depth-contour being clearly predicted.

From left to right, the indicated trend passes through nearly symmetrical unimodal samples (relatively size independent) to fine skewed and extremely fine skewed sediment representing mixtures of the two main modes with the coarse mode dominant. Continuing around the curve, skewness values decrease to zero for samples containing approxi-

mately equal modal proportions, and skewness is negative for the remaining samples, which are composed predominantly of the clay mode with a very small amount of coarser material. If additional samples consisting of 100 per cent clay size material were available for this region, it is assumed that they would cause the trend to reverse once again with the subsequent symmetrical values of skewness indicating a return to a unimodal condition.

Additional evidence of the relationship of skewness to mean size may be had by referring back to the contour maps of these two parameters (Figs. 28 and 30).

Mean Size versus Kurtosis. The extreme sensitivity of kurtosis to slight additions (2–10%) of a second mode to a primary mode is strikingly illustrated in the scatterplot of mean size and kurtosis (Fig. 34). A well developed coarse mode, at approximately 3ϕ , quickly passes from a mesokurtic condition into one of extreme leptokurtosis with the addition of about 5 per cent of a secondary mode. Increasing amounts of the fine mode, up to 20–25 per cent, causes a subsequent decrease in leptokurtosis until the fine mode makes up about 25–30 per cent of the sediment, at which point a return to mesokurtosis occurs. Platykurtosis results when the two main modes are mixed in subequal amounts with maximum platykurtosis prevailing at a 50–50 modal ratio.

If the clay mode were present, the curve would extend on up into extreme leptokurtosis values and then return to mesokurtosis to complete the entire cycle. The uniform distribution of values about the curve is probably characteristic of the uniform, gradational energy pattern of the neritic environment—fluvial sediment showing a marked tendency to cluster (Folk and Ward, 1957, p. 20) as a result of a fluctuating energy budget.

Scatter in the region coarser than 5ϕ is caused by the inconsistency of the size of the coarse mode; it will be recalled that sorting causes a progressive size decrease of the coarse mode in the offshore direction. If the coarse mode remained constant, as it would if it were inherited from a particular source area, there would be no scatter and an environment other than neritic would be indicated.

Mean size-kurtosis variation therefore has usefulness as an environmental indicator based on the degree of spread (cluster) and on the presence or absence of scatter in the $2-6\phi$ region.

Standard Deviation versus Skewness. The relationship of standard deviation and skewness can be established theoretically (Folk and Ward, 1957, p. 20) as being a circular trend; unimodal samples with good sorting and equal mixtures of two modes with the poorest possible sorting both will yield symmetrical skewness values, whereas 75:25 mixtures of the two modes will yield the most nonsymmetrical skewness values. The top half of the trend is exhibited fairly well (Fig. 35), with a clustering of samples having a coarse to fine mode ratio of 3 to 1 in the region of very poor sorting and positive skewness.

The significance of the relationship between skewness and sorting was indicated by the discovery that kurtosis indicated trimodality. Mixtures of two well developed modes will result in sediments which fall on the circular trend, but mixtures of one well developed mode and one poorly sorted mode result in sediments which depart from the curve. From Figure 35 it will be noted that the unimodal beach sediment is symmetrically skewed and possesses uniformly good sorting. Progressing in a clockwise direction around the trend, additions of the poorly sorted secondary mode (which actually is a mixture of two lesser modes) causes departure from the ideal circular trend. Increased

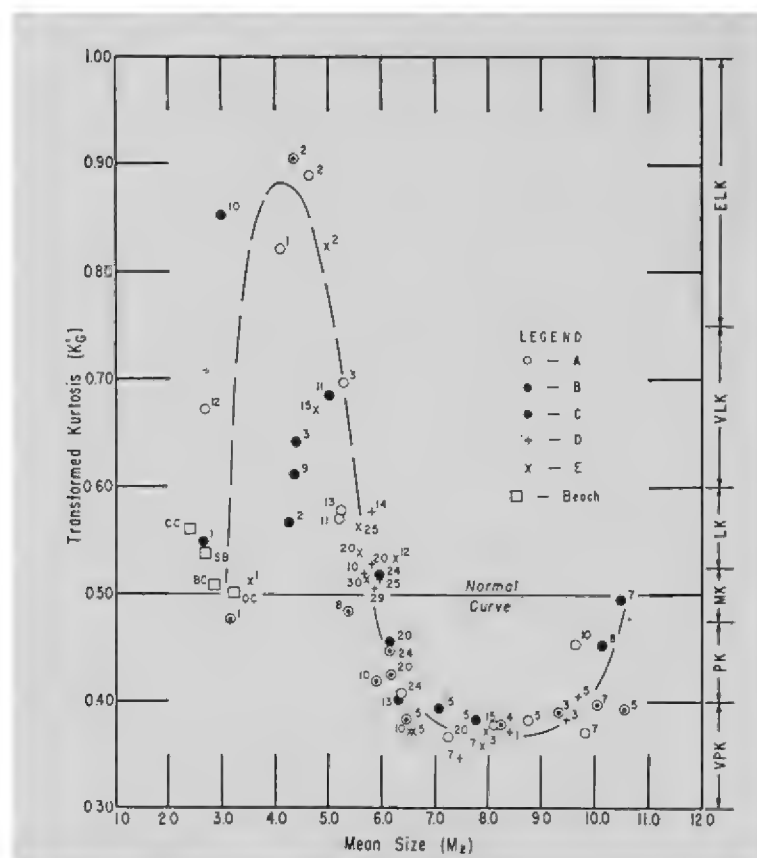


FIG. 34. Scatterplot of mean size and transformed kurtosis.

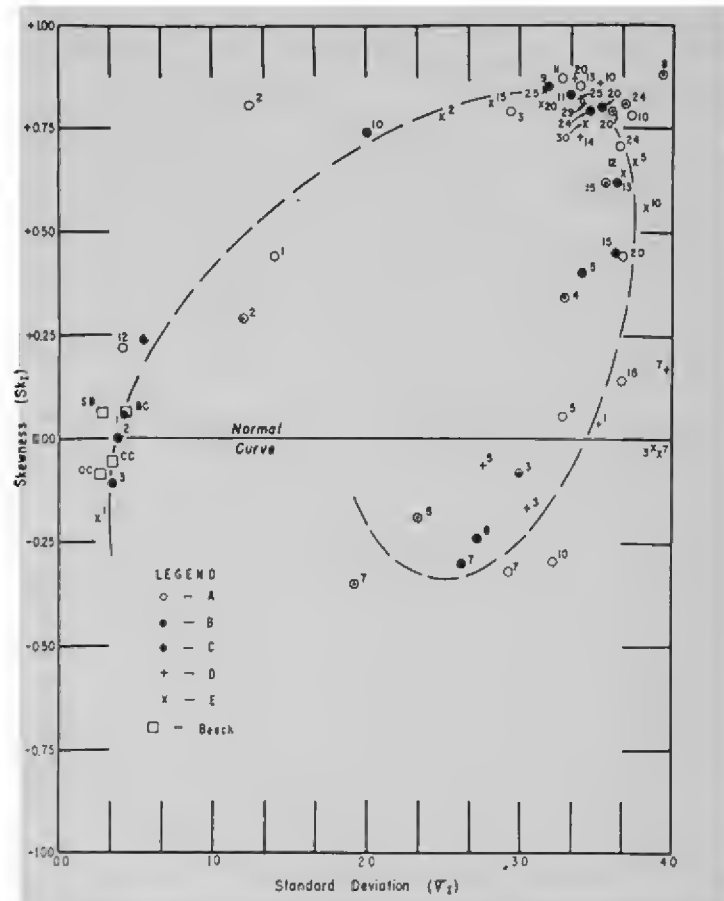


FIG. 35. Scatterplot of standard deviation and skewness.

departure results with increasing additions of the poorly developed fine mode, reaching an extreme when the fine mode predominates, as is indicated by the randomness of the negative skewed samples. Because of the inherent poor sorting of clay the indicated trend does not return to low values of standard deviation, but rather terminates at a higher value of standard deviation which represents the maximum sorting obtainable by 100 per cent clay.

Bivariant plots of skewness and standard deviation have now been established as possessing usefulness in determining the relative degree of development of modes and in ascertaining the polymodal nature of sediment.

Standard Deviation versus Kurtosis. The relationship between sorting and kurtosis is shown in Figure 36. Once again, poor sorting of the fine mode accounts for the scatter in the platykurtic samples. Starting with the unimodal beach samples possessing good sorting and normal kurtosis, a slight addition of clay causes extreme leptokurtosis, reaching a peak at $1.5 \bar{V}_1$. Increased additions of the fine mode up to 20–30 per cent, cause a return to mesokurtosis and a shift to poorer sorting. Mixtures of approximately equal amounts of the two modes cause platykurtosis and poorest sorting. Further additions of the fine mode in excess of 50 per cent cause the trend to reverse and to terminate in a region of slightly better sorting and mesokurtosis.

Two groups of sorting values are easily noted, either the sediments are very well sorted and unimodal or they are poorly sorted and polymodal.

Skewness versus Kurtosis. A number of interesting relations appear on the plot of skewness versus kurtosis (Fig. 37). First is the lack of samples with normal skewness and kurtosis, with only the unimodal beach samples falling into this category. Second, although symmetrically skewed very platykurtic samples are relatively abundant, there are no symmetrically skewed extremely leptokurtic samples. As Folk and Ward (1957, p. 21) explain, in order for an extremely leptokurtic sediment to be symmetrically

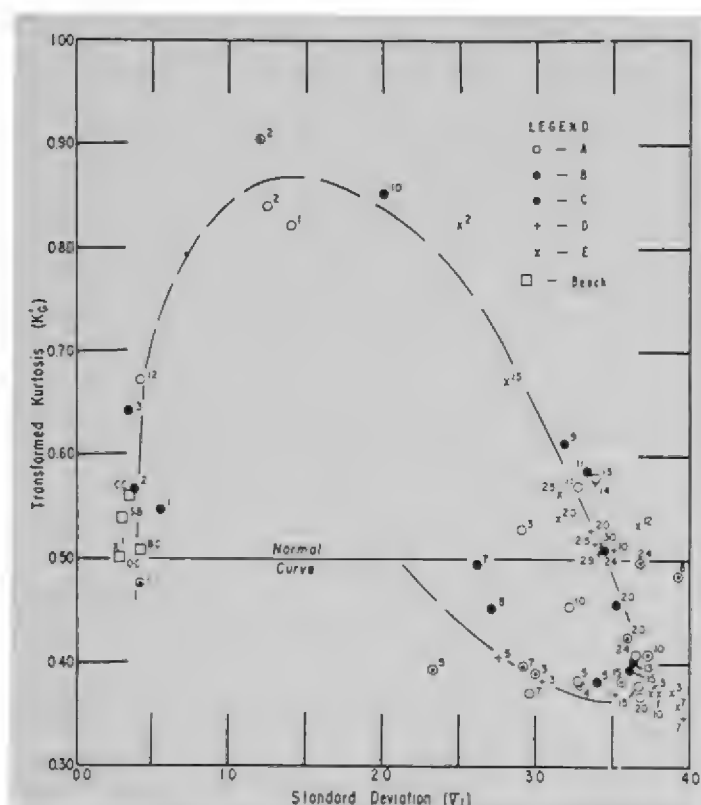


FIG. 36. Scatterplot of standard deviation and transformed kurtosis.

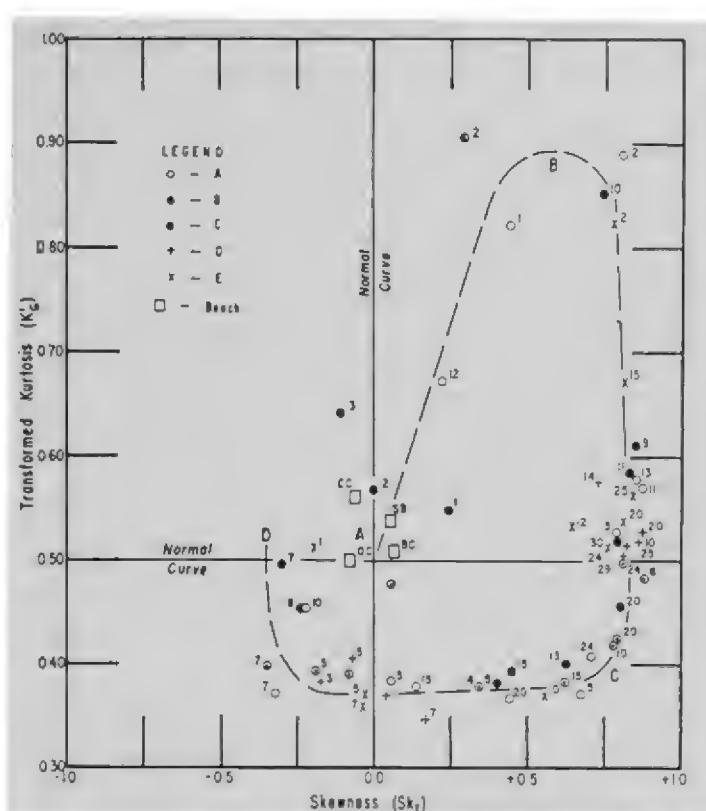


FIG. 37. Scatterplot of skewness and transformed kurtosis.

skewed it would have to have both a coarse and a fine tail in exactly equal amounts; in other words, a trimodal sediment with a very pronounced middle mode. No such samples were present in the study area.

The significant feature of this plot is the well developed trend with only two or three samples departing at all from the trend. The reason for this is that skewness and kurtosis are related in such a manner that they react similarly to sorting and, therefore, when they are plotted against one another the effect of sorting cancels out. This is fortunate, as it permits examination of sediment with poorly developed modes, so as to determine the modality independently of the obscuring effect of sorting.

The trend (Fig. 37) represents the following sediment variation: Unimodal samples, at A, exhibit normal kurtosis and are symmetrical. Slight additions of a second mode cause extreme leptokurtosis and positive-skewness, B; additions in excess of 5–7 per cent and less than 20 per cent cause the sediment to remain positive-skewed, but to return to a mesokurtic condition. Increasing amounts of the fine mode make the sediment platykurtic (but still positive-skewed), and at C a change in direction occurs where the samples remain platykurtic and become progressively more symmetrical, normal symmetry being acquired when the modes are present in equal amount. The curve stops at D for the suite of samples from the study area because of the poor development of the clay mode. (If the clay mode were well developed the remainder of the cycle would be similar and opposite to the half just described.)

Four-dimensional Relationship. Folk and Ward (1957), in a gravel-sand bar on the Brazos River, have accurately plotted a helix illustrating the interrelationships of all four of the grain size parameters to each other in one plot.

The sediments examined in this report extend their four-dimensional plot into the region of finer sizes and indicate the validity of such a helical model in the sand to clay size range also. In the writer's opinion, careful analysis of bivariate plots and, in particular, contour maps of the individual parameters, offers the most fruitful field for determining the environment and predicting directional trends of ancient sediments.

MINERALOGY

Mineralogy of the coarse fraction ($> 4.5\phi$) only will be discussed in this section, clay mineralogy being reserved for later independent treatment.

Light Minerals. Canada Balsam mounts of the light minerals were made for all the samples subsequently examined for heavy mineral content. The light fraction is rather uniform within the study area and consists predominantly of subangular quartz, with some feldspar (probably derived from the Colorado River drainage area or, in a remote sense, from the crystalline rocks of northeastern New Mexico) and variable amounts of organic material. Mineralogically, the offshore sediment is classified as subarkose, containing 15–25 per cent feldspar and 75–85 per cent quartz. Beach samples are predominantly quartzose, containing more than 95 per cent quartz, and compositionally fall in the orthoquartzite clan (Folk, 1954). Metamorphic rock fragments were not detected in any of the sediments.

Glauconite occurs throughout the study area with the exception of the beach and surf zone. Most of it is fresh, frequently showing striations; generally it has a larger grade size than the terrigenous minerals—both characteristics indicating formation in place, with no, or very little, subsequent transportation. Material in the study area always occurred as well rounded pellets. Glauconite, although common and persistent, comprised less than one per cent of the sediment and therefore was not included in the mineral counts.

Shell Fragments. Shell fragments are not plentiful in the study area except in samples of sediment from the topographic highs, where they constitute about 50 per cent of the sample, the other 50 per cent being sand. All other samples contain less than 2–3 per cent shell, which comprises the coarsest size grade of the sediment. Pelecypod fragments make up the bulk of shell material; much smaller amounts of echinoid spines and a few ostracod valves making up the remainder of the shell. The presence of echinoid spines in almost all the samples seems to confirm the conclusion drawn by Shepard and Moore (1955, Fig. 28) that echinoid spines are characteristic of the open Gulf.

Heavy Minerals. Heavy mineral distribution is a powerful tool for the three-dimensional interpretation of a sedimentary body. In this study sorting factors have been judged to exhibit a minor influence, permitting the determined heavy mineral suite to be analyzed in terms of source areas.

Figure 38 illustrates the relative abundance of heavy minerals in respect to the coarse decant cut of each sample. The areas of the circles are directly proportional to numerical values of percentage by weight, which are also indicated. Slightly higher percentages are obtained in most of the eastern part of the area, indicating a “dilution” of the central and western parts resulting from a paucity of heavy minerals currently being contributed by the Brazos. The present siltload of the Brazos River is derived primarily by erosion of the predominantly second cycle Cenozoic sedimentary rocks of the Coastal Plain, bank erosion between Waco and the Gulf accounting for essentially the entire siltload of the Brazos. Any of the less stable minerals which have not already been removed from the mineral suite of these sedimentary rocks may not exist after outcrop weathering and subsequent transportation down the Brazos. However, the Beaumont clay is unique. It possesses an abundance of hornblende derived from erosion of the Central Mineral Region during the Pleistocene Epoch. The hornblende is carried only a short

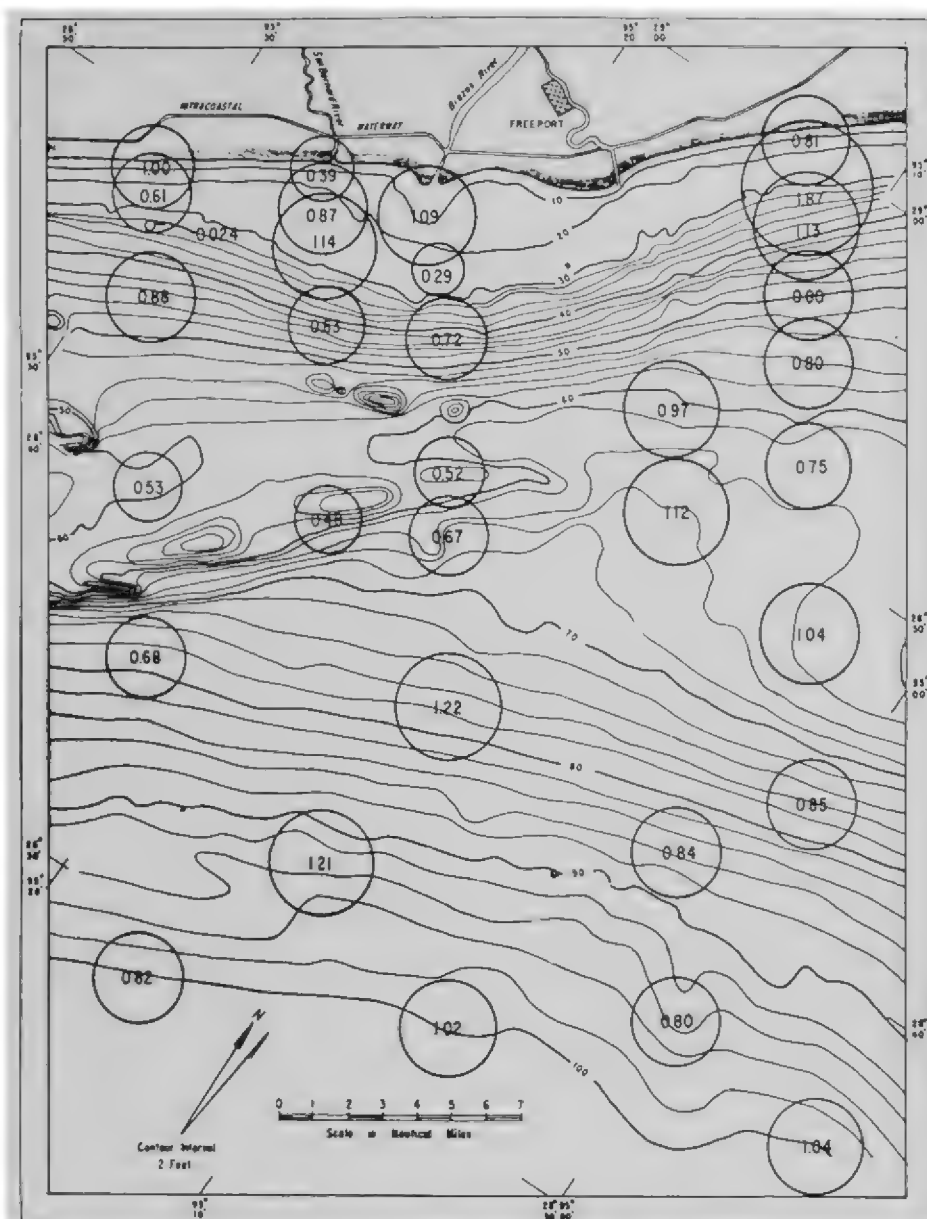


FIG. 38. Distribution of heavy mineral fraction relative to gross decant cut. Numbers represent percentage by weight.

distance to the Gulf, so that a small percentage of relatively unstable minerals are actually included in the Brazos suite.

Local variations, probably caused by small scale patterns and the sampling procedure, were observed in the percentages by weight of heavy minerals in the nearshore zone where offshore bars were developed. If a sample were taken from a ripple ridge it would contain almost no heavy minerals, but if it were obtained from the adjacent ripple trough it would contain an abnormally high percentage of heavy minerals.

In the study area the most abundant heavy minerals are hornblende, zircon, epidote, garnet, tourmaline, rutile, and apatite; basaltic hornblende, clinozoisite, enstatite, monazite, staurolite, and zoisite are common. Rarer and less persistent minerals include actinolite, anatase, andalusite, biotite, muscovite, diopside, hypersthene, kyanite, piemontite, sillimanite, titanite, tremolite, and wollastonite. Bullard's (1942) description of the heavy minerals from the adjacent beach sand applies also to the heavy minerals from the study area. Relative abundances of the important mineral species are graphically indicated on maps described in the following paragraphs. Hornblende in the area was of two types, the blue-green soda-rich variety so characteristic of the Colorado River drainage area and the more common green-brown variety. Garnet carried by the present Brazos River is confined to the bottom sediment immediately adjacent to the mouth of the Brazos, and possesses distinctive mammillary etching which definitely characterizes

modern Brazos River material. Dullnig (1957) concluded from studying heavy minerals of the Brazos River that mammillary etched garnet occurs throughout the drainage area of the river system, being most abundant in the Pennsylvanian outcrop.

Tables 4 and 5 indicate the relative abundances of each heavy mineral species in percent, and Figures 39, 40, 41, and 42 show the distribution of the more abundant diagnostic minerals. Once again, areas of the circles are directly proportional to percentage relative abundance. Hornblende exhibits a fairly uniform distribution (Fig. 39) except in the region immediately adjacent to the mouth of the Brazos, where it is deficient, and in the region just offshore to the east, where percentages are high. The pattern for epidote (Fig. 40) is similar to that for hornblende, although for epidote the pattern is much more pronounced.

Garnet (Fig. 41) and zircon (Fig. 42), in contrast, indicate a distribution reversed to that of hornblende and epidote. Garnet is extremely abundant in and adjacent to the mouth of the Brazos, but is present only in decreased amounts to the east. The same situation prevails with respect to zircon, except that it is even more deficient in the eastern part.

For all four of the mineral species plotted, the distribution over the seaward half of the area (the submerged deltaic plain) in general is consistently uniform, and suggests that the assemblage in this area is inherited and that erosion (or non-deposition) is taking place. The distribution could also be explained if the sediment had become homogeneous by long submergence. This evidence fits in with a consideration of the equilibrium profile in that an "obstacle" will undergo grading to the extent of bringing it into proper configuration with the profile.

Following Bullard (1942), the writer found it very informative to split the heavy mineral suite into a less resistant group (andalusite, biotite, epidote, hornblende, hypersthene, apatite, basaltic hornblende, enstatite, diopside, clinozoisite, zoisite, tremolite, wollastonite, and actinolite), and a more durable group (anatase, garnet, kyanite, monazite, rutile, sillimanite, staurolite, titanite, tourmaline, and zircon). These percentages are plotted in Figure 43, the area of the solid-line circles representing the percentage of more durable minerals, and the area of the dashed-line circles representing the percentage of less resistant minerals. The relationship suggested by the relative distributions discussed above is now emphasized. A less resistant assemblage is dominant to the east, while a more durable suite prevails adjacent to the mouth of the Brazos River and to the west. Bullard (1942) has analyzed a series of samples from the Brazos River for some distance upstream. His conclusion that the river carries an ultra-stable assemblage of heavy minerals is in agreement with the conclusion drawn previously on the basis of heavy mineral abundance. Since the Brazos River and the bottom sediment in the region of the Brazos delta carry a more durable mineral suite, which is in marked contrast to that characteristic of the remainder of the study area, the obvious conclusion is that deposition of heavy minerals from the Brazos River is diluting the existing suite of less resistant minerals already present in the area.

As the present Brazos River suite of heavy minerals is not representative of the offshore area as a whole, some other source must be found. In the outcrops of Cenozoic sedimentary rocks from the Colorado River to west-central Louisiana, Cogen (1940, p. 2090-2094) found a hornblende assemblage confined to outcrops within the drainage area of the Colorado River, an epidote assemblage from the Colorado River northeast to the Trinity River where the suite interfingers with a dominant kyanite assemblage, which

TABLE 4
Heavy mineral analysis
(per cent by number of grains; for each sample counts of 100 grains each were made)

Sample no.	A-1	A-2	A-3	A-5	A-10	A-15	A-24	B-1	B-2	B-3	B-5	B-10	B-20	C-1	C-2	C-4	C-8	C-10	C-15	C-24	D-7	D-10	D-20	D-25	E-1	E-2	E-3	E-5	E-7	E-10	E-15	E-20	E-30	
Actinolite	1	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	1	....	....	....	....	....	....	....	....	....
Anatase	1	....	....	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	1	....	....	1	....	....	....	....	....	....
Andalusite	1	....	....	....	....	....	....	1	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	1	....	....	....	....	....	....	1	1	....	....
Apatite	2	12	13	11	3	4	....	2	7	6	6	6	6	3	8	9	3	7	9	7	4	2	1	5	3	5	4	6	4	4	9	2	4	....
Basaltic hornblende	4	1	2	5	4	6	4	1	1	....	1	1	1	2	2	4	2	1	4	3	2	9	5	3	5	3	3	2	5	4	6	1	1	....
Biotite/ Muscovite	....	4	7	10	....	2	3	5	2	....	4	6	1	2	....	....	2	1	2	....	4	3	1	5	....	1	2	6	4	1	2	1	1	....
Clinozoisite	2	2	2	3	3	4	3	....	....	....	3	....	3	2	2	5	....	3	2	2	....	....	1	2	2	2	2	3	....	3	....	1	3	....
Diopsite	1	2	1	....	....	....	....	1	1	....	2	....	....	....	....	1	1	2	....	....	1	1	3	1	1	1	1	1	2	....	2	2	....	
Enstatite	1	3	2	3	....	2	5	1	1	3	2	2	7	....	2	4	3	....	3	2	4	1	4	5	2	1	3	2	3	2	4	4	8	....
Epidote	4	13	11	11	11	14	15	4	1	18	2	8	13	2	10	15	7	11	10	6	13	19	8	9	15	17	18	21	21	16	9	12	18	....
Garnet	12	13	11	4	12	6	3	14	16	15	7	6	12	21	8	3	19	7	7	8	15	7	9	12	8	14	9	6	8	10	6	7	9	....
Hornblende	9	10	26	23	24	39	25	14	11	15	25	28	33	3	17	31	18	22	30	27	28	29	35	31	26	26	31	17	29	21	20	28	25	....
Hypersthene	....	1	....	....	1	....	....	....	....	3	....	....	....	....	6	1	....	....	1	....	....	....	....	....	1	1	....	....	2	1	....	3	....	....
Kyanite	1	....	....	4	3	1	1	1	....	....	1	....	....	2	2	1	1	....	....	2	1	1	....	....	1	....	....	3	....	....	1	1	1	....
Monazite	1	2	....	1	1	1	3	4	5	3	2	4	1	2	2	....	3	1	3	2	....	1	1	2	1	2	4	2	1	1	....	4	1	....
Piedmontite	....	....	....	....	1	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
Rutile	5	9	2	6	3	3	6	2	4	4	2	1	1	14	9	2	1	4	3	5	1	....	1	1	3	3	1	4	1	5	2	1	3	....
Sillimanite	....	....	1	....	....	....	....	....	....	....	....	1	1	....	....	....	....	1	1	....	....	....	....	....	....	....	....	1	....	....	1	1	....	....
Staurolite	3	3	1	1	4	2	4	....	2	2	4	2	....	3	2	2	3	4	1	2	1	1	1	1	5	....	1	2	3	5	2	6	2	....
Titanite	2	....	....	....	1	1	3	1	....	....	1	....	....	3	1	1	....	1	1	....	1	....	1	....	4	....	....	1	....	....	1	1	1	....
Tourmaline	10	4	5	2	6	3	4	22	8	2	12	6	4	11	1	2	6	3	4	2	5	5	4	4	13	4	2	2	8	4	7	8	1	....
Tremolite	....	1	1	....	....	1	....	1	1	1	2	1	2	....	....	....	1	1	3	2	3	3	1	....	1	1	1	1	2	....	....	1	....	....
Wollastonite	....	....	....	2	....	....	....	1	2	....	1	1	....	....	....	1	....	....	1	....	....	....	....	....	....	1	....	....	....	....	1	1	....	....
Zircon	30	19	14	12	21	11	19	23	37	28	21	27	14	27	28	14	29	29	11	25	16	27	24	17	4	17	18	17	7	18	18	13	21	....
Zoisite	6	1	1	2	2	2	2	1	....	....	2	....	1	2	....	4	1	2	3	5	1	....	....	1	3	1	....	3	....	5	8	1	1	....

TABLE 5
Supplement to heavy mineral analysis

Sample no.	Per cent heavy fraction	Estimated size (Phi)	Per cent black opaques
A- 1	1.00	4.1	49
A- 2	0.61	4.4	45
A- 3	0.024	4.4	43
A- 5	0.88	4.5	24
A-10	0.53	3.8	39
A-15	0.68	3.8	21
A-24	0.82	3.9	36
B- 1	0.39	2.5	50
B- 2	0.87	4.6	45
B- 3	1.14	4.6	59
B- 5	0.63	4.4	34
B-10	0.48	3.8	25
B-20	1.21	3.5	22
C- 1	1.09	3.3	53
C- 2	0.29	4.2	81
C- 4	0.72	3.6	34
C- 8	0.52	3.1	29
C-10	0.67	3.4	38
C-15	1.22	3.6	18
C-24	1.02	3.6	37
D- 7	0.97	3.4	37
D-10	1.12	3.3	22
D-20	0.84	3.5	32
D-25	0.80	3.6	24
E- 1	0.81	3.6	20
E- 2	1.87	4.1	50
E- 3	1.13	3.8	36
E- 5	0.80	3.9	33
E- 7	0.80	4.1	29
E-10	0.75	3.6	38
E-15	1.04	3.8	27
E-20	0.85	3.5	24
E-30	1.04	3.5	25

continues on into Louisiana. A similar petrologic trend in the subsurface Cenozoic formations was established by Bornhauser (1940, p. 133). The presence of large quantities of hornblende in the Pleistocene Series (and to a lesser extent in the Pliocene-Miocene) of Colorado County, Texas, has been pointed out by Bailey (1923). Goldstein (1942) divided the border of the Gulf of Mexico into petrologic provinces, including a Western Gulf Province, a Mississippi River Province, and a Transition zone between them. Characteristic suites of the Mississippi River and Western Gulf Provinces are similar, except that the former contain large amounts of pyroxene whereas the latter is almost completely lacking in pyroxene; amphibole, epidote, ilmenite, and biotite are common to both suites. As part of API Project 51, van Andel and Poole (1960) have presented essentially the same results as Goldstein obtained.

Because kyanite is absent or lacking in significant amounts in the sediment of the study area it may be assumed either that sediment derived from the northeast is not being transported into the area offshore from the Brazos River or that not enough of this material is entering the Gulf to produce a noticeable effect.

Hornblende is therefore supplied by either the Colorado or Mississippi rivers. Furthermore, pyroxene, particularly augite, is characteristic of the Mississippi River assemblage, but in contrast these minerals are minor constituents of the Colorado River and

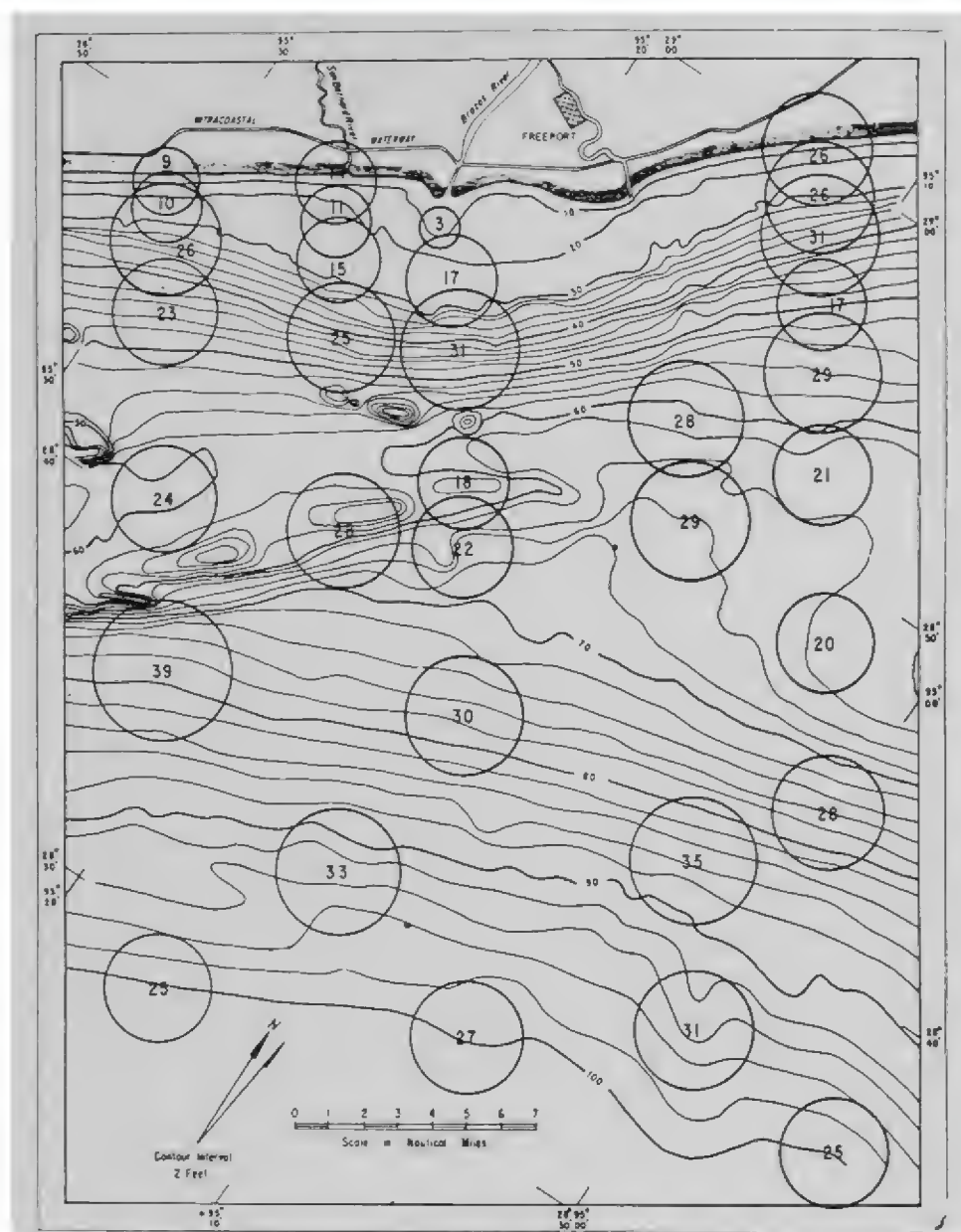


FIG. 39. Distribution of hornblende. Numbers in per cent.

study area assemblages. The implication, of course, is that the Colorado River is the source of the particular heavy mineral assemblage found offshore from the Brazos.

The history of the Colorado River explains the wide distribution of Colorado River material in the northwestern Gulf of Mexico. This river is well known for frequently shifting its lower course during historic time, and a similar prehistoric wandering tendency is recorded in the Pleistocene formations of the Gulf Coast. Wadsworth, who mapped the different stream courses of the Colorado during Pleistocene and Recent time, states (1941, p. 49-50) :

"After leaving the Tres-Palacios stage {represented by late Beaumont deposition} the river flowed southeastwardly to empty, with the Brazos River, into what must have been an inland bay of considerable size. This bay occupied the region of southeastern Matagorda County and southwestern Brazoria County. The presence of such a bay is indicated by occurrences of salt water in shallow water wells found in the vicinity of Hawkinsville. At the suggestion of Weaver, the writer interprets these occurrences as connate Gulf or Bay water trapped in sand lenses at the time the river was building its delta.

The Caney stage is so named by the writer because it is believed that Caney Creek, similar to Tres-Palacios Creek, represents the final remnant of a former prominent distributary {sic} channel of the Colorado River.

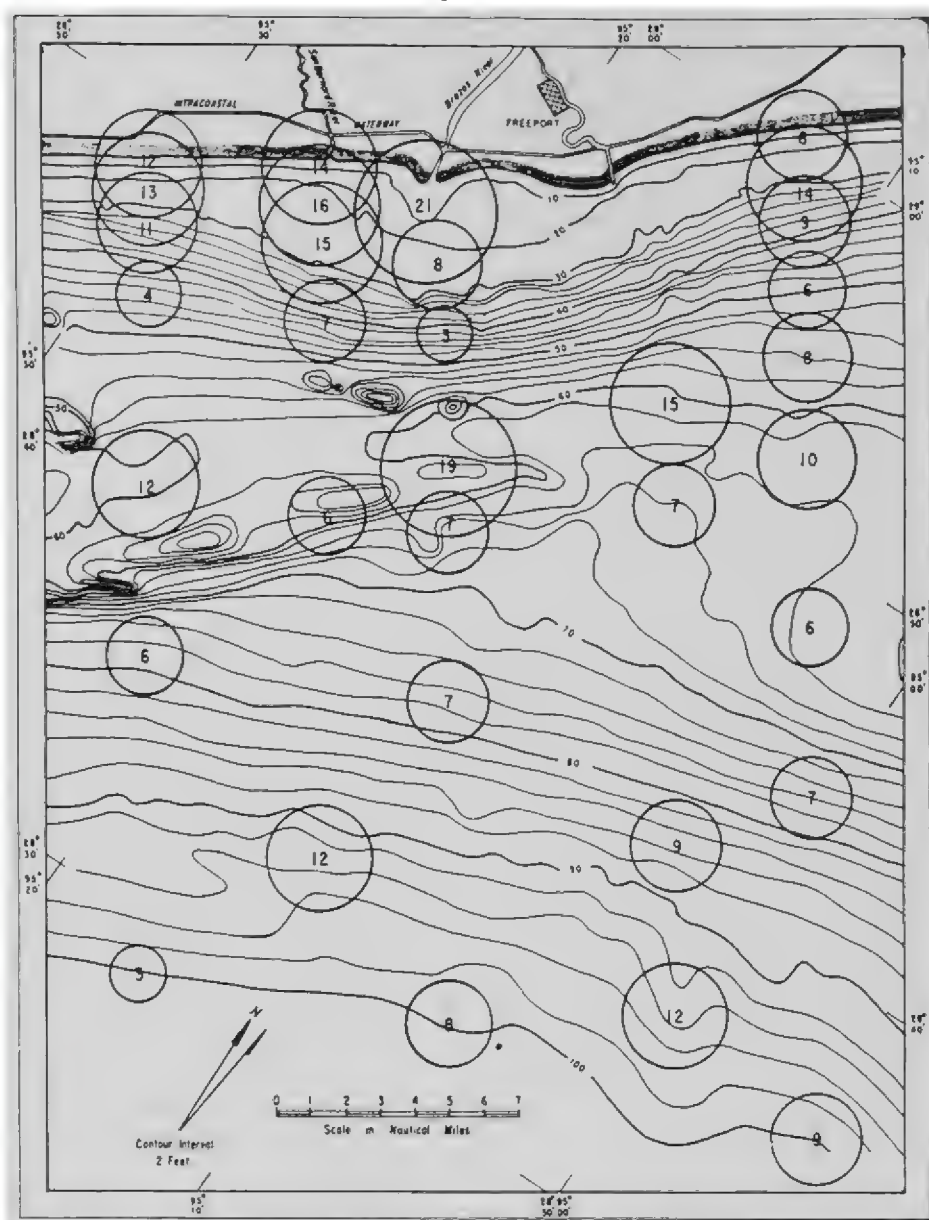


FIG. 40. Distribution of epidote. Numbers in per cent.

A large amount of sediments reached sea level in this area at that time, since the two largest rivers in Texas were emptying loads into the Bay only a few miles apart. The resultant delta is one of the most striking on the Texas Gulf Coast. The entire bay area was filled and the mainland was pushed seaward over the barrier beach until it is now in direct contact with the Gulf of Mexico. It is interesting to note that this is one of only two similar places on the Texas coast. The other being in the vicinity of High Island {sic}.

The river occupied the Caney stage probably in early Recent times. It maintained this position until late Recent, and then shifted westward to occupy its present position."

The extensive erosion and deposition that followed the last great Pleistocene lowering of sea level, during which time the Colorado and Brazos rivers enjoyed a common delta, account for the characteristic Colorado River mineral assemblage in the northwestern Gulf of Mexico. The heavy mineral suite of the Colorado River would be expected to dominate over that of the Brazos River in this period because the Colorado was deriving its sediments from a primary source area rich in accessory minerals (Central Mineral Region) as opposed to the Brazos, which was reworking sedimentary rock already much reduced in heavy mineral content.

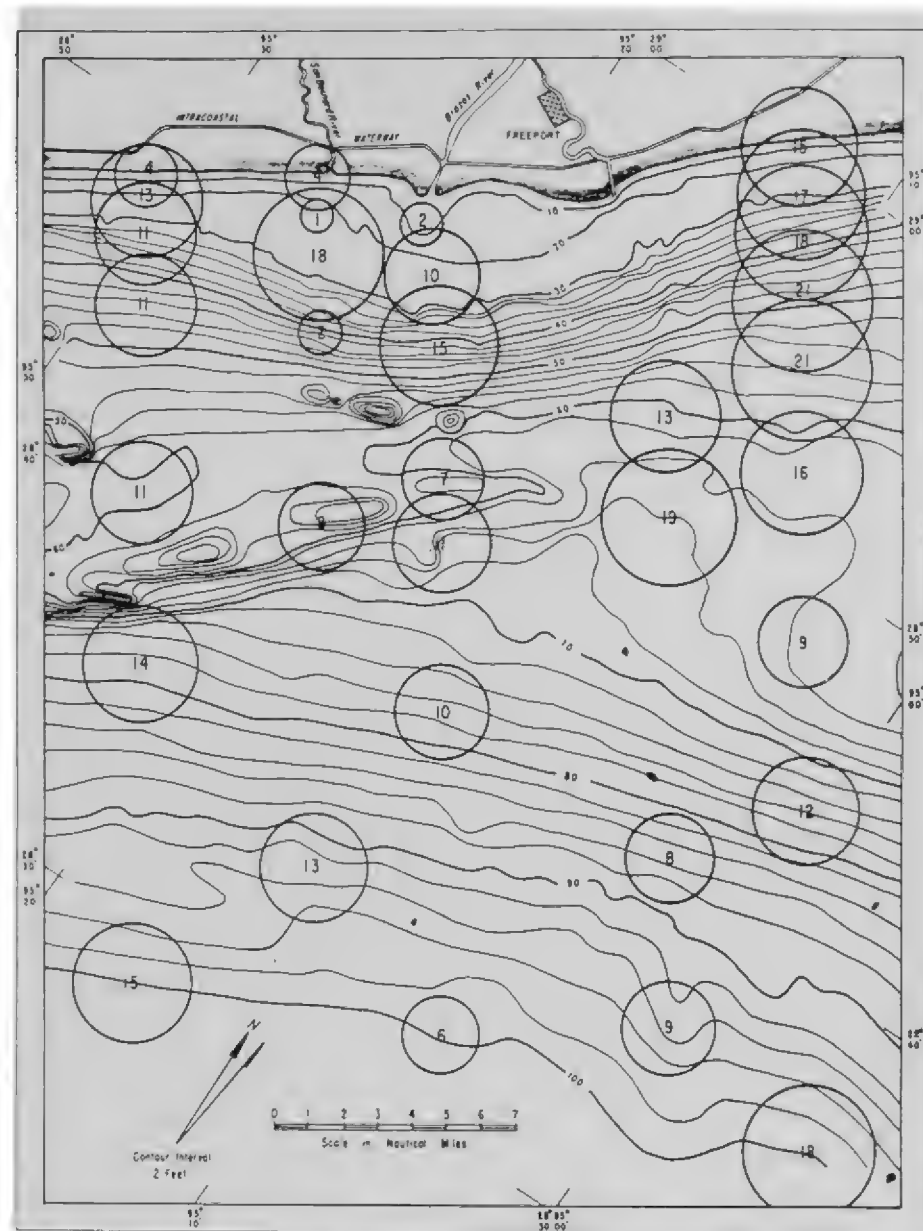


FIG. 41. Distribution of garnet. Numbers in per cent.

Effects of longshore currents and storm waves on the heavy mineral distribution in this same area is effectively summarized by Goldstein (1942, p. 84) :

"In summation, it would seem that sediment from the present Mississippi River is being swept slowly but surely to the west, diluted by the contributions of streams along the coast, perhaps mixed with sediment carried from the southwest by storms or currents, and exchanging with and being contaminated by reworked Pleistocene sediments upon the continental shelf."

Some admixture of material from the Mississippi River and the Rio Grande in the study area is indicated by a trace of basaltic hornblende in all the samples. Basaltic hornblende, however, is an extremely durable mineral and for this reason is not too significant. An admixture of less resistant minerals from the Mississippi River and the Rio Grande would afford much more impressive evidence for mass transportation by longshore currents.

CLAY MINERALS

Identification. The montmorillonites exhibited properties which divided them into two groups. The first group exhibited a 14 AU periodicity, was difficult to expand to 17 AU and collapsed shortly after treatment, and upon heating developed a diffuse but obvious 14 AU peak. These properties can best be explained in terms of a poorly devel-

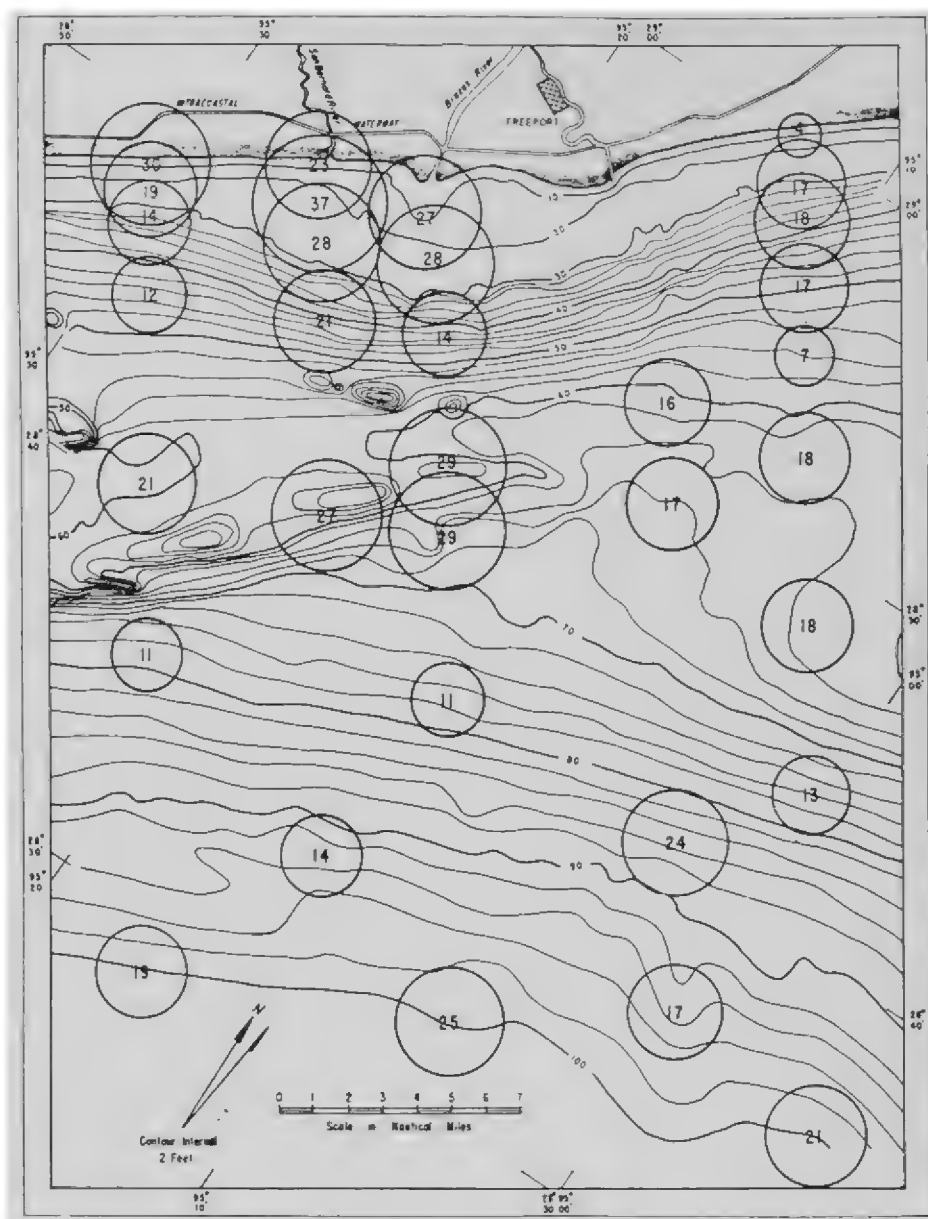


FIG. 42. Distribution of zircon. Numbers in per cent.

oped chlorite-montmorillonite mixed-layer phase with montmorillonite in much greater abundance. Montmorillonite also occurs in a mixed-layer condition with illite in some of the samples.

Grim and Johns (1954, p. 86-87) describe a montmorillonite from recent sediments in the Rockport, Texas, area and account for its properties by means of scattered "islands of brucite" forming in an interlayer position. Possibly the better crystallized material in the study area represents an advanced state of interlayer brucite development upon prolonged exposure to a marine environment.

The second group of montmorillonites displayed a first order peak in the region of 15.0 to 15.8 AU, indicating a predominance of calcium ions in the exchange position. The possibility of an organic complex not affected by the oxidation treatment arises in respect to some of the basal spacings larger than 15.5 AU.

No particular problems were encountered in the identification of illite, and no effort was made to resolve the 10 AU peak with respect to illite and detrital mica. Rather sharp 10 AU peaks result from the well developed crystallinity of clay in the study area.

As anticipated, a great deal of difficulty was experienced in attempting to differentiate between chlorite and kaolinite. (Only recently have clay mineralogists become concerned with the chlorite problem, previously assigning kaolinite to the 7 AU peak entirely, a fact which must be considered when consulting the literature on the subject.)

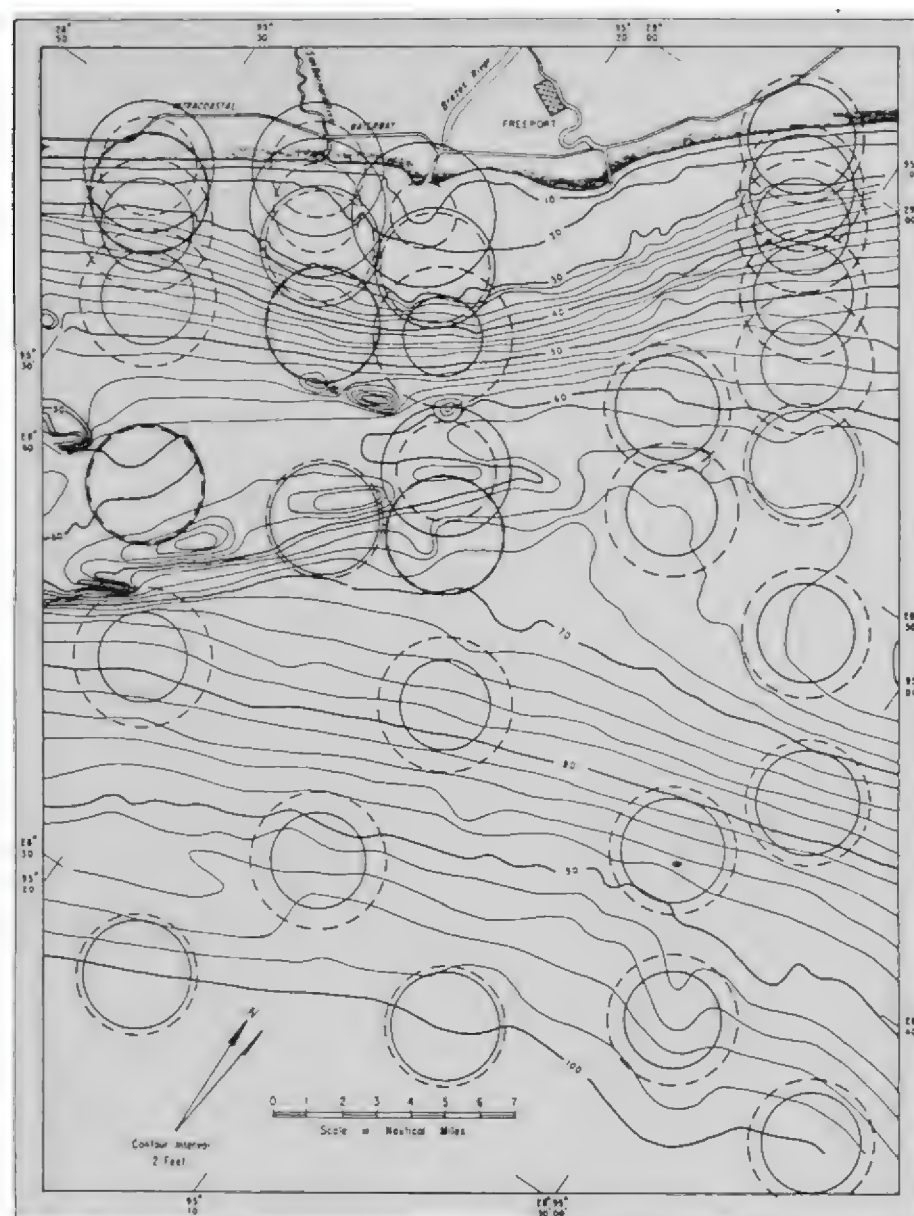


FIG. 43. Relation of more durable (solid lines) to less resistant (dashed lines) heavy minerals. Areas of circles proportional to percentages.

Chlorite/kaolinite are present in subordinate quantities in the study area so that the 14 AU peak, if one existed, was obscured by the large diffuse montmorillonite peak. Spectrometer traces of a series of samples heated in increasing 50°C increments indicated a modification of the (001) reflections to occur at 550–600°C. At this temperature the 14 AU peak, if present, is increased in intensity and most of the higher order peaks are reduced in intensity or disappear. Kaolinite is amorphous at this temperature so that any peak remaining at 7 AU at 650°C must be attributed to chlorite. Absence of the peak indicates only that either chlorite or kaolinite were present originally. Because montmorillonite is collapsed to 10 AU at 650°C the 14 AU peak is resolved and positively establishes the presence or absence of chlorite. On many samples the (005) chlorite peak (2.8 AU) was pronounced and increased in intensity upon heating. These features are characteristic of clinochlore (Weiss and Rowland, 1956a) and are an additional means of identification of chlorite in the sample suite.

A significant difference exists between chlorite in the study area and chlorite from Texas Bays in the Rockport area in regard to their relative degrees of crystallinity. In their analyses of the Rockport sediment in conjunction with American Petroleum Institute Project 51, Grim and Johns (1954, p. 87) report thermal modification, correspond-

ing to that described in the preceding paragraph, at a temperature of 400–500°C. Evidence of superior crystallinity coupled with the occurrence of chlorite and chloritoid in the coarse fraction ($> 5\phi$) suggests a detrital origin for the chlorite in the study area as contrasted to that of the Rockport area.

Quantitative Estimations. From an examination of spectrometer traces of samples spread over the entire study area, it became apparent that a great deal of quantitative variation existed between the samples. In an effort to establish the nature and direction of this variation, a method of quantitative estimations based on comparison of relative peak heights within each specific sample was adopted. In many respects it is similar to the procedure adopted by John, Grim, and Bradley (1954) for use in analyzing recent clay. Clay contained in recent sediment generally possesses relatively poor crystallinity and is intimately mixed in addition to being in a state of flux in regard to its cation exchange properties. For this reason they defy a completely accurate analysis on the basis of clay mineral species, and as a result quantitative estimations are necessarily not as precise as might be desired. Numerical results obtained from quantitative estimations therefore have greatest significance when they are rounded off and various small errors cancel out.

In order to provide a means of comparison of peak heights within each sample, illite is arbitrarily chosen as unity and the other constituents compared to it. This procedure eliminates the effects of sample to sample variation and, furthermore, compares minerals of the same relative degree of crystallinity, this last mentioned factor making absolute comparisons with well crystallized reference minerals impossible. Illite is well suited for its role as it is present in all of the samples and possesses a unique, clearly defined peak at 10 AU.

Relative abundances of illite and montmorillonite are determined from the glycolated sample by comparing the heights of the 10 AU and 17 AU peaks. Before these peaks can be compared directly a correction must be made to compensate for the structure factor of montmorillonite type minerals. From the curve of the form factor for montmorillonite it is determined that scattering efficiency at angles corresponding to 17 AU exceeds that at angles corresponding to 10 AU by a factor of approximately four. For comparative purposes, then, the 10 AU peak height on the glycolated sample is multiplied by four before comparing with the 17 AU peak height to determine the relative amounts of illite and montmorillonite in the sample.

The procedure with respect to chlorite and kaolinite is much more complicated because of the difficulty of distinguishing between the two. Comparison of the heights of the 3.3 AU (illite) and 3.5 AU (chlorite, kaolinite and montmorillonite) peaks is possible based on the assumption that scattering in this restricted high angle range is roughly comparable for the three minerals. The problem, then, is to assign chlorite and kaolinite their respective portions of the 3.5 AU peak. The contribution of montmorillonite may be automatically subtracted by employing the data from the glycolated sample for chlorite-kaolinite computation. Intensity variations resulting from heating of chlorite minerals (Weiss and Rowland, 1956a and 1956b) indicate that the 14 AU peak resulting from ignition to 650°C is, on the average, 5/3's as intense as the 3.5 AU peak in the unheated condition. As the form factor for chlorite is extremely variable, depending on the specific type of chlorite mineral in question and on the amount of iron present, this 5/3's figure is very general and gives an approximation.

The contribution of kaolinite to the 3.5 AU peak on the glycolated sample may be determined by subtraction of the above determined value of chlorite from the peak. As the 3.3 AU peak on the glycolated sample represents both illite and montmorillonite (3.3 being the 5th order of 17), reference must be made back to the untreated sample. This may be done simply by multiplying the intensity of the 3.5 AU peak on the glycolated slide by the ratio of the intensities of this peak on the untreated and glycolated slides respectively. Finally, a correction for quartz contamination is made by subtracting the intensity of the 4.25 AU quartz peak from the 3.3 AU illite peak on the untreated sample (John, *et al.*, 1954, p. 250).

An example of the above procedure is given for sample E-30 in Table 6, which lists

TABLE 6
Relative intensity data for sample E-30

17 AU	14 AU	10 AU	7 AU	3.5 AU	3.3 AU	Comments
-----	-----	-----	383	204	474	(Untreated sample)
-----	-----	-----	-----	-----	442	Illite corrected for quartz
765	-----	246	210	173	666	(Glycolated sample)
-----	-----	984	-----	-----	-----	Illite corrected
-----	-----	-----	-----	125	-----	3.5 AU peak corrected
-----	265	-----	24	22	725	(Ignited sample)
-----	159	-----	-----	125	-----	Chlorite corrected
-----	(approx.)	-----	-----	-----	-----	Kaolinite

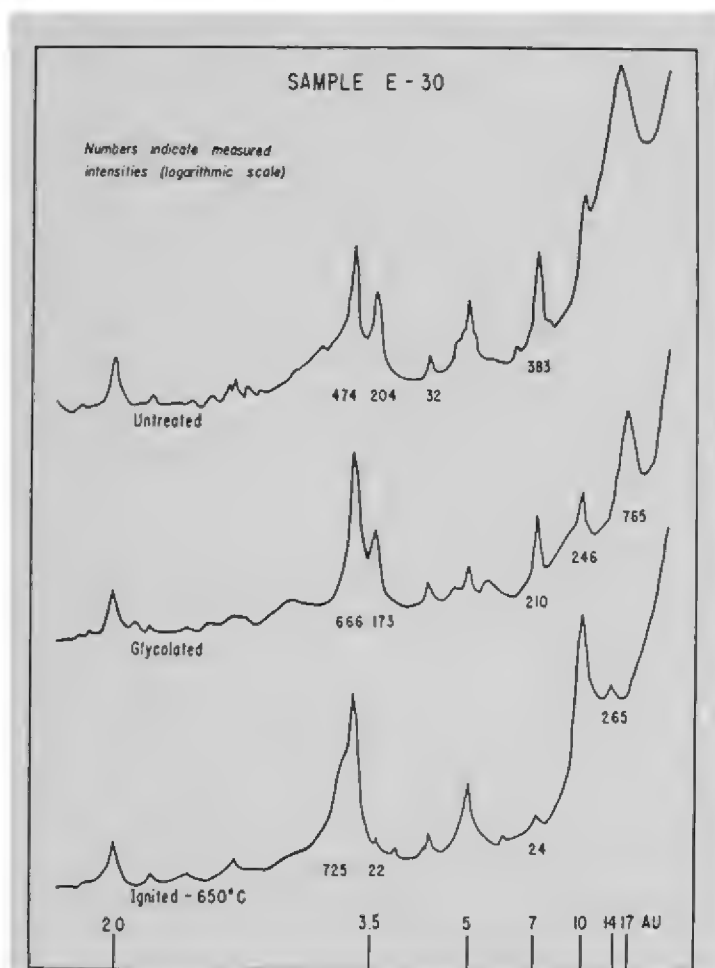


FIG. 44. Spectrometer traces for sample E-30 in the air-dried, glycolated, and ignited states.

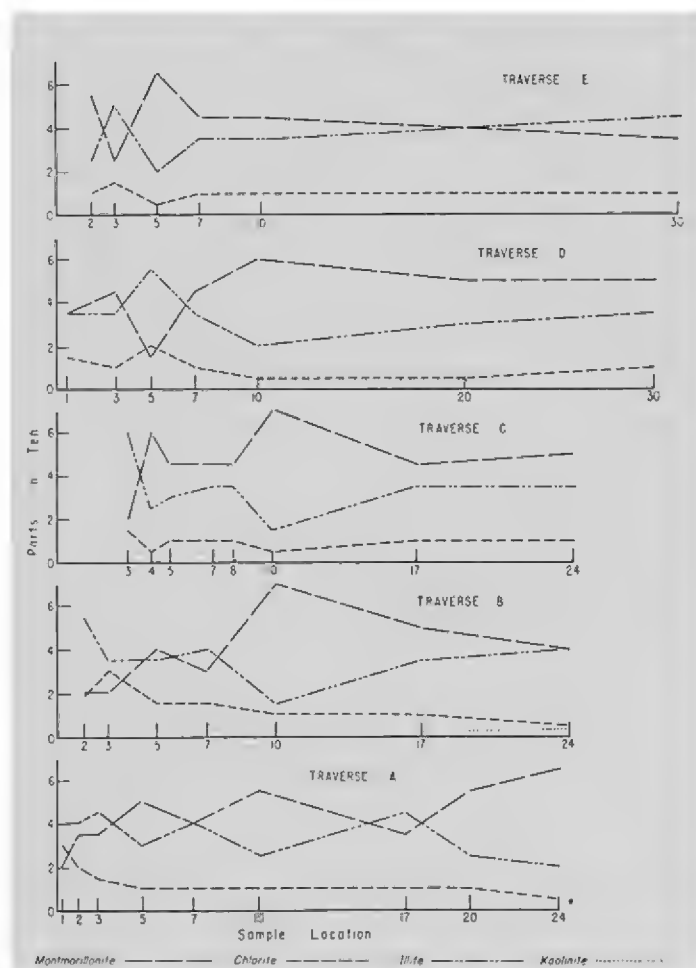


FIG. 45. Profiles of relative abundance in parts in ten of major clay mineral constituents.

TABLE 7
Clay mineral composition for sample E-30

Montmorillonite	Chlorite	Illite	Kaolinite	Comments
0.78	0.28	1.0	-----	Parts per one part of illite
37.8	13.6	48.5	-----	Approximate percentage of each constituent
3.5	1.0+	4.5	-----	Parts in 10 of each constituent allowing 10 per cent for material not registering

data obtained from the spectrometer traces illustrated in Figure 44, and Table 7, which is a compilation of the results of the analysis.

The value for chlorite (Table 6) has been rounded off inasmuch as the approximate corrected value is slightly high. Although the procedure for determining the relative amounts of chlorite and kaolinite is rather complicated and subject to some error, the aggregate percentage of these two minerals with respect to the total clay fraction is small, being on the order of 5–10 per cent; therefore, even large errors in this part of the analysis will not cause any significant variation in the relative percentages of the other main constituents and should not be considered a serious drawback to the procedure as a whole. Final results are presented as parts in 10 of each constituent for the total clay mineral composition allowing 10 per cent for material not registering, and are rounded off to the nearest half, which is consistent with the accuracy of the method.

Table 8 lists the results of quantitative analysis of a number of samples from the study area. The relative nature of this data may be made clear by an example. Sample A-7 contains 4.0 parts montmorillonite, 1.0 parts chlorite, and 4.0 parts illite; that is, the sample has equal amounts of illite and montmorillonite, four times as much illite as chlorite, and kaolinite is absent. The data should not be interpreted as meaning exactly 30 per cent more illite is present than chlorite, and so on. Individual components may be compared from sample to sample, however. In comparing sample A-7 with sample A-24 (6.5 parts montmorillonite, 0.5 parts chlorite, 2.0 parts illite) it may be assumed that A-24 contains 25 per cent more montmorillonite, 5 per cent less chlorite, and 20 per cent less illite than A-7. Another factor to be kept in mind is that the clay mineral amounts are based on the clay fraction of the sediment as 100 per cent. In order to make comparisons between different samples in respect to absolute amounts of the different clay minerals present, it would first be necessary to reduce the data in terms of the percentage of total clay in the sample.

Distribution. Distribution of the various clay mineral constituents is shown diagrammatically for each of the traverses in Figure 45. Chlorite content is fairly uniform and is minor in comparison to illite and montmorillonite, the latter two functioning reciprocally. There is a suggestion of a trend of increasing montmorillonite from the beach to about 10 miles offshore followed by a subsequent decrease and levelling off in a seaward direction. In addition it seems that montmorillonite is low and illite high directly adjacent to the beach. In the farthest seaward portion of the study area all three main clay mineral constituents occur in uniform relative amounts.

Any series of random samples might also show the same variation. In order to test the significance of the most pronounced variation (mentioned above at approxi-

TABLE 8

Most probable clay mineral composition in parts in 10 allowing 10 per cent for material not registering

Sample	Depth (feet)	Basal reflection (AU)	Montmorillonite	Chlorite	Illite	Kaolinite
AUC (Brazoria, Texas)	Flood plain	15.2	3.5—	1.5	4.0+	.....
A- 1	8	.....	2.0	3.0	4.0+	.....
A- 2	23	14.5	3.5—	2.0	4.0	.....
A- 3	33	15.2	3.5+	1.5—	4.5—	.....
A- 5	45	15.8	5.0	1.0	3.0	.....
A- 7	54	14.7	4.0	1.0	4.0	.....
A-10	61	14.7	5.5	1.0	2.5+	.....
A-17	84	14.7	3.5	1.0	4.5	.....
A-20	92	.....	5.5	1.0	2.5	.....
A-24	100	15.2	6.5	0.5	2.0	.....
B- 2	22	14.5	2.0	2.0—	5.5—	.....
B- 3	27	11.3	2.0	3.0	3.5+	0.5
B- 5	42	14.9	4.0	1.5	3.5+	.....
B- 7	56	15.0	3.0+	1.5	4.0+	.....
B-10	57	15.2	6.5	1.0	1.5	.....
B-17	84	15.8	5.0—	1.0—	3.5—	TR
B-24	100	15.0	4.0	0.5	4.0	0.5—
C- 3	32	15.2	2.0	1.5—	6.0—	.....
C- 4	42	15.3	6.0—	0.5+	2.5	.....
C- 5	51	14.7	4.5+	1.0	3.0+	.....
C- 7	62	15.5	4.5	1.0	3.5	.....
C- 8	56	15.4	4.5—	1.0	3.5+	.....
C-10	67	14.7	7.0	0.5	1.5+	.....
C-17	84	14.4	4.5	1.0	3.5	.....
C-24	100	15.4	5.0	1.0—	3.5—	.....
D- 1	21	.....	3.5+	1.5	3.5+	.....
D- 3	37	15.0	4.5+	1.0	3.5—	.....
D- 5	53	.....	1.5	2.0	5.5	.....
D- 7	61	15.2	4.5—	1.0	3.5+	TR
D-10	66	14.9	6.0	0.5	2.0	0.5
D-20	85	15.7	5.0	0.5—	3.0+	0.5
D-29	100	15.8	5.0—	1.0—	3.5	.....
E- 2	30	14.7	5.5+	1.0—	2.5	.....
E- 3	38	15.2	2.5	1.5	5.0+	.....
E- 5	49	14.5	6.5—	0.5+	2.0	.....
E- 7	56	14.3	4.5+	1.0	3.5	.....
E-10	63	15.5	4.5	1.0	3.5	.....
E-30	100	15.0	3.5	1.0+	4.5	.....

mately 10 miles offshore), data for this point was compiled and tested statistically by means of the t-test. Results indicated a probability of 0.17.

A sample from the flood plain of the Brazos River at Brazoria, Texas, about 20 miles upstream from the Gulf, indicated 3.5 parts montmorillonite, 1.5 parts chlorite, and 4.0 parts illite. Assuming this ratio to be representative of material arriving in the Gulf, it may be concluded that differential deposition and source area account for the clay mineral distribution in the study area. This follows strictly from a consideration

of the *relative* proportions of clay mineral constituents and accounts for the mineralogical trend only. Volumetric comparisons are impossible due to the nature of the analytical method employed.

It is observed, then, that illite and chlorite are preferentially deposited from suspension prior (closer to shore) to montmorillonite; thus montmorillonite exhibits greatest deposition farther seaward, in this situation about 10 miles offshore. Beyond this point montmorillonite content decreases and at approximately 17 miles offshore ceases, probably marking the offshore limit of significant deposition of Brazos River material. Seaward, clay mineral character is either inherited from older deltaic sediment or the Brazos suite of clay minerals is being deposited intact, probably at a slow rate.

The above conclusions are supported by consideration of the color distribution of clay in the study area. Clay derived from the Brazos River is characteristically red, and because of this property may be easily traced offshore. Despite the olive color of the gross bottom sediment due to organic material, the true color of the clay fraction may be ascertained by simple mechanical separation of the clay or by the addition of a very small amount of oxidizing agent. Red clay extends from the beach out to the shoal area (60-foot depth-contour), at which point it tends to become olive. The limit of deposition of Brazos River material, as indicated by red clay, is essentially the same as that determined by considering the minerals of the clay fraction.

Grim and Johns (1954, p. 95) found similar proportions of clay minerals in the Gulf of Mexico offshore from the barrier islands in the vicinity of Rockport, and also reported an improved crystallinity of the chloritic phase in this offshore region corresponding to that in the study area.

In the writer's opinion no positive evidence exists in favor of diagenesis in the area under discussion. The fact that red color of the clay has not been destroyed in such a potentially reducing environment does not favor diagenesis. Higher temperatures necessary for thermal modification plus the development of sharp peaks on diffraction patterns indicate a detrital source for the clay in question instead of a diagenetic origin.

Distribution of the four main clay mineral types in the study area may be summarized as the result of both selective deposition and source area. Furthermore, diagenesis is not causing any significant changes in the clay mineral suite.

FORAMINIFERA

A selected group of samples from the study area from depths of 61–92 feet were examined for the purpose of determining all of the species of Foraminifera present. Table 9 shows the results of this study, listing 101 species. Most abundant genera were *Elphidium* and "*Rotalia*," and *Bigenerina*, *Bolivina*, *Bulimina*, *Cibicides*, *Cibicidina*, *Discorbis*, *Eponides*, *Nonionella*, *Planulina*, *Pseudoclavulina*, *Quinqueloculina*, *Rectobolivina*, *Reussella*, *Textularia*, *Uvigerina*, and *Virgulina* were common. Pelagic genera included *Globigerinella*, *Globigerinoides*, and *Globorotalia*, but were, on the whole, rather rare in the study area. A few pyritized tests were also identified from heavy mineral mounts.

The thanatocoenose content of the coarse fraction ($> 4.5\phi$) was less than one per cent on the average, indicating either an "old shelf deposit" or a "reworked delta deposit" (Shepard, 1956, p. 2570). This evidence supports previous statements to the effect that the portion of the study area seaward of the 60-foot depth-contour is an

TABLE 9

Distribution of Foraminifera in the area offshore from the Brazos River, Texas

Station Depth	A-10 61'	C-10 67'	E-10 63'	A-20 92'	C-20 92'	E-20 76'
<i>Ammobaculites salsus</i>	--	--	X	--	--	--
<i>A. sp. A</i>	--	--	X	--	--	X
<i>A. sp.</i>	--	X	--	--	--	X
<i>Ammoscalaria pseudospiralis</i>	--	--	--	--	X	--
<i>Bigenerina irregularis</i>	X	X	X	X	X	X
<i>Bolivina fragilis</i>	X	--	X	X	--	--
<i>B. lowmani</i>	--	X	X	--	--	X
<i>B. minima</i>	X	--	X	X	X	--
<i>B. pulchella primitiva</i>	X	X	X	X	X	X
<i>B. simplex</i>	--	X	--	X	X	--
<i>B. striatula</i>	--	X	X	--	--	X
<i>B. subaenariensis mexicana</i>	X	--	--	--	--	--
<i>B. subspinescens</i>	--	X	--	--	--	--
<i>B. sp.</i>	--	--	X	--	X	--
<i>Bulimina affinis</i>	--	--	--	--	X	--
<i>B. marginata</i>	--	--	--	--	X	--
<i>B. striata mexicana</i>	--	--	--	--	X	X
<i>B. tenuis</i>	--	--	--	--	--	X
<i>Buliminella cf. bassendor fensis</i>	--	X	X	--	--	X
<i>B. elegantissima</i>	--	--	X	--	--	X
<i>Cancris oblonga</i>	--	X	X	--	X	X
<i>Cassidulina norcrossi australis</i>	--	--	--	X	--	--
<i>Cibicides concentricus</i>	X	X	X	X	X	X
<i>C. cf. concentricus</i>	X	X	X	--	X	X
<i>C. io</i>	X	X	--	X	X	X
<i>C. robustus</i>	X	X	--	X	X	--
<i>C. umbonatus</i>	--	--	--	--	X	--
<i>C. sp. 1</i>	--	--	--	X	--	--
<i>Cibicidina strattoni</i>	--	X	X	--	--	X
<i>Discorbis bertheloti</i>	X	--	X	--	X	X
<i>D. candeiana</i>	--	--	--	--	--	X
<i>D. floridana</i>	--	--	--	--	X	X
<i>D. floridensis</i>	X	--	--	--	X	--
<i>Eggerella bradyi</i>	--	--	--	--	X	--
<i>Ehrenbergina spinea</i>	--	--	--	--	X	--
<i>Elphidium discoidale</i>	X	X	X	X	X	X
<i>E. fimbriatulum</i>	--	--	--	X	--	--
<i>E. cf. fimbriatulum</i>	X	--	X	--	X	X
<i>E. galvestonense</i>	X	X	X	--	--	X
<i>E. gunteri</i>	X	X	X	X	X	X
<i>E. incertum mexicanum</i>	X	X	X	X	X	X
<i>Elphidium sp. cf. e. koeboeense</i>	--	X	X	--	--	X
<i>E. poeyanum</i>	--	--	X	--	--	--
<i>E. translucens</i>	--	X	--	--	X	X
<i>Epistominella vitrea</i>	--	X	--	--	--	--
<i>Eponides antillarum</i>	--	--	X	--	--	--
<i>E. haunai</i>	X	X	--	X	--	X
<i>E. polius</i>	--	--	X	--	--	X
<i>E. regularis</i>	--	--	--	--	X	--
<i>Gandryina (pseudogandryina) atlantica</i>	--	--	--	X	--	--
<i>Globigerinella acquilateralis</i>	--	--	--	--	--	X
<i>Globigerinoides rubra</i>	X	--	--	X	X	X
<i>Globorotalia punctulata</i>	--	--	--	X	--	--
<i>Guttulina australis</i>	--	X	X	--	--	X
<i>Gyroidina soldanii altiformis</i>	--	--	--	--	X	--
<i>Lagena</i>	--	--	--	--	--	X
<i>Loxostomum truncatum</i>	--	--	X	X	X	X
<i>Marginulina planata</i>	--	X	--	--	--	--
<i>Nodosaria</i>	--	--	X	--	X	--
<i>Nonionella atlantica</i>	X	X	X	X	X	X
<i>N. opina</i>	--	X	X	--	--	--
<i>N. cf. opina</i>	X	--	--	--	--	--
<i>Planulina exorna</i>	--	X	--	X	X	X

TABLE 9—Continued

Distribution of Foraminifera in the area offshore from the Brazos River, Texas

Station Depth	A-10 61'	C-10 67'	E-10 63'	A-20 92'	C-20 92'	E-20 76'
<i>Protonina difflugiformis</i>	--	--	--	--	X	--
<i>Pseudoclavulina mexicana</i>	X	--	--	X	--	--
<i>Pullinia bulloides</i>	--	--	--	--	--	X
<i>Pulleniatina obliquiloculata</i>	--	--	--	--	X	--
<i>Quinqueloculina bicostata</i>	--	--	--	--	X	--
<i>Q. compta</i>	X	--	--	X	X	--
<i>Q. horrida</i>	X	--	--	X	--	--
<i>Q. lamarekiana</i>	--	X	--	--	--	--
<i>Q. poeyana</i>	--	X	X	--	--	X
<i>Q. cf. vulgaris</i>	X	--	--	--	--	--
<i>Q. sp. cf. q. compta</i>	--	--	X	--	--	--
<i>Rectobolivina advena</i>	--	X	--	X	X	X
<i>Reussella atlantica</i>	X	X	X	X	X	X
" <i>Rotalia</i> " <i>beccarii</i>	X	X	X	X	X	X
" <i>R.</i> " <i>beccarii</i> variant A	X	X	X	X	X	X
" <i>R.</i> " <i>beccarii</i> variant B	X	X	X	X	--	X
" <i>R.</i> " <i>pauciloculata</i>	X	X	--	--	--	--
" <i>R.</i> " <i>rolshauseni</i>	X	--	X	X	X	X
" <i>R.</i> " <i>translucens</i>	X	X	X	--	--	X
<i>Sigmoilina schlumbergeri</i>	--	--	--	--	X	--
<i>Siphonina pulchra</i>	--	--	X	--	X	X
<i>Siphotextularia affinis</i>	X	X	X	--	--	X
<i>S. rolshauseni</i>	--	X	--	--	--	X
<i>Textularia foliacea occidentalis</i>	--	--	--	--	X	--
<i>T. mayori</i>	--	X	X	--	X	X
<i>T. cf. mayori</i>	--	X	--	--	--	--
<i>T. mexicana</i>	--	--	--	X	X	--
<i>Triloculina trigonula</i>	--	--	X	--	--	--
<i>Uvigerina peregrina parvula</i>	--	--	X	X	X	--
<i>U. hispidocostata</i>	--	--	--	X	--	--
<i>Virgulina complanata</i>	X	--	--	X	X	--
<i>V. compressa</i>	--	--	--	X	X	--
<i>V. mexicana</i>	X	X	--	--	--	--
<i>V. pontoni</i>	--	X	X	X	X	X
<i>V. spinicostata</i>	X	--	X	- X	--	X

old delta. Observation of the coarse fraction also showed most of the individuals to be air-filled, indicating a predominantly living population (Phleger, 1951, p. 82).

A comprehensive study of the Foraminifera of the Gulf of Mexico from a depth of about 75 feet on into the Sigsbee Deep was made by Phleger (1951) from samples obtained during the 1947 cruise of the Woods Hole Oceanographic Institution research vessel "Atlantis." Two of the traverses of this cruise extend into the study area, and although Phleger does not include data for samples taken from the shallow end of these traverses, a close correlation does exist between the foraminiferal distributions of his deeper water samples and those determined for the study area. Occurrences in the study area, however, do extend the shallow limits (Phleger, 1951) of some species into somewhat shallower water. Essential agreement is also present between the study area distribution and the open-Gulf facies of the Mississippi Sound (Phleger, 1954), San Antonio Bay (Parker, *et al.*, 1953), and Mississippi delta (Phleger, 1955) areas.

Summary and Conclusions

The composite energy spectrum of the study area results in a marked symmetrical configuration of the modern delta of the Brazos River. This delta is comparable to other

modern deltas in that it possesses poorly sorted sandy topset beds, extensive foreset beds dipping at 1–2° and grading from sand and silt to mud and clay in deeper water, and thin bottomset beds. A clay belt lying 8–10 miles off the mouth of the Brazos is also characteristic of the delta. Longshore currents are not significant as far as shaping the delta is concerned, but they do distribute the mineral suite to the southwest. The limit of effective deposition of material from the Brazos is approximately 10–17 miles offshore in 60–70 feet of water, and beyond this point sand size material is supplied from a source farther offshore.

Sediment in the study area can be accurately interpreted in terms of its modality, which is the result primarily of sorting by waves and secondarily of source area. From the beach seaward a series of well developed coarse modes, decreasing in size from fine sand to medium silt offshore, are combined with progressively increasing amounts of a poorly sorted fine (clay) mode to about 60 feet of water, where the fine mode is predominant. At this boundary topographic highs occur which contribute a second coarse (sand) mode to the sediment. Material of intermediate size (6–10 ϕ) is essentially lacking in the area.

Skewness and kurtosis, considered independently, are effective indicators of the modal character of the sediment, and when plotted versus one another describe the relative proportions of the modes independent of sorting in any specific sample. Bivariate plots of mean size and kurtosis, mean size and skewness, and standard deviation and kurtosis, also indicate the relative proportions of each mode in the sediment.

Development of the individual modes in regard to sorting is evident from the plot of standard deviation and skewness, whereas the plot of mean size and kurtosis indicates the consistency of specific modal grain sizes in a group of sediments. Best sorting occurs in the unimodal beach samples, intermediate sorting in the predominantly clay samples, and poorest sorting in subequal mixtures of these two end members.

Mean size and standard deviation together shape a trend, the position of which, in respect to absolute values of sorting, distinguishes the littoral and neritic environment from the fluvial environment. Direction to the shoreline is determinable from frequency plots of skewness, predominantly positive-skewed values indicating proximity to the shoreline and predominantly negative-skewed values indicating an offshore location.

Topography is reflected directly by mean size and indirectly by other parameters characterizing the modality of the sediments. Mean size and depth vary in uniform manner from shore to the 60-foot depth-contour, a break in slope of the trend occurring at 25–30 feet marking the depth of maximum marine erosion. Specific trends of these two variables distinguish variations in sediment supply at particular localities and, therefore, are of correlative value. Topographic breaks in slope are precisely marked by abrupt changes in values of standard deviation, signifying poor sorting of sediments at these points due to the mechanics of sorting by waves.

Geologic history of the area is reflected in the heavy mineral distribution, which is the result of coalescence of the Brazos and Colorado river deltas during late Pleistocene and early Recent time. After these two rivers had built an extensive delta and completely filled in a large bay, the Colorado River once again shifted its course and in late Recent time was discharging into Matagorda Bay. The more durable heavy mineral suite currently carried by the Brazos is diluting the existing less resistant suite in the region immediately adjacent to the mouth of the Brazos.

The shoal area seaward of the 60-foot depth-contour represents a submerged deltaic plain formed during the last major Pleistocene lowering of sea level.

Clay mineral distribution is the result of selective deposition of detrital clay from the Brazos, with no evidence of diagenesis occurring upon deposition.

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Experiments With Engineering of Marine Ecosystems¹

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Abstract

Moderate sized ecosystem cultures were attempted in concrete ponds simulating some principal bay types found on the Texas Coast: (a) the reef-plankton brackish bay, (b) the grassy bottom, and (c) the blue-green algal flats. Processes and successional changes within the engineered systems were monitored with diurnal curve methods. Some general aspects of photosynthesis, community respiration, and organismal dominance were similar to those of the bay prototypes.

The relative role of respiration and reaeration was delimited in several experiments. In a sequence of extreme salinity shocks, one oyster reef-bay system exhibited rapid metabolic recovery and successive diatom blooms like that in San Antonio Bay.

Some experimental means for partial replication of artificial ecosystems were tested with concrete reef ponds in triplicate. High alkalinity regimes at controlled salinity were developed with evaporation and freshwater inflow sequences like that in some Texas river estuaries. pH control was also demonstrated with carbon dioxide gas injections from tanks. Over a six-month period a semi-anaerobic system replaced an aerobic system. It was shown that a pollution-resembling syndrome could gradually emerge from a more normal aerobic system where there was initial inorganic nutrient fertilization. The graphs resembled some based on data from upper Galveston and Nueces Bays. The low nighttime oxygen regime was a climax for the summer weather regime. Pyrhelium data were used to compute efficiencies of gross photosynthesis (0.8—3%), in utilizing the visible wave lengths somewhat less than in the bay prototypes.

In a large concrete pond, a grassy bottom system without stratification provided populations of diatoms, zooplankton, and foraminifera with diurnal variations, trace element concentrations, and metabolic quotients like those in Redfish Bay and Aransas Bay.

In very shallow ponds, heavy blue-green algal mats once transplanted, were maintained with large diurnal oxidation and reduction changes and high metabolic quotients like those in parts of the Laguna Madre.

Some similarity of processes and concentration levels maintained in these artificial ecosystems may justify their use for controlled experimental study of the bays.

Introduction

In previous papers measurements of gross photosynthesis and system respiration were reported for various bays along the Texas coast (Odum and Hoskin, 1958; Odum and Wilson, 1962; Odum, 1963; and Odum, Cuzon, Beyers, and Allbaugh, 1963). The metabolic measurements indicated the functional state of these ecosystems under influences of seasonal change, pollution, dredging, and other experimental changes. In such large bays, the investigations were restricted to the natural experimental situations fortuitously provided. For further study of these bays, some smaller models were needed in which controlled experimental manipulations might be feasible.

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In 1960 and 1961, to meet the need for experimental ecosystems, plastic and concrete ponds were built. Attempts were made to develop formulae for culturing ecosystems with ecological engineering methods. By selection of depth, salinity, and mechanism of circulation, conditions in several bays were simulated and these ponds were heavily seeded with water, muds, and organisms from the several bay prototypes. This is a report of the metabolic patterns which resulted in 4 types of ecosystem cultures in these ponds.

Conditions in the pond systems were devised to simulate three important bay ecosystem types. The first type was the low salinity, turbid bay containing oyster bars in which a biogeochemical cycle was maintained that included the phytoplankton-producing water circulating over the concentrations of sessile reef consumers, filter-feeding and releasing nutrients from the reefs. Copano, San Antonio, and Matagorda Bays were examples. A plastic system (Fig. 1A) in 1960 was continued with concrete systems in 1962 (Fig. 1B). The second type was the shallow grassy bottom bay at about 30‰ with much of the photosynthesis by benthic plants such as parts of Redfish and Aransas Bays. The large pond (Fig. 1C) was used. The third type was the system of blue-green algal mats carpeting the thin-water flats of part of the Laguna Madre often under hypersaline conditions. Shallower, smaller ponds were used for these (Fig. 1D).

ECOSYSTEM CULTURING, ECOLOGICAL ENGINEERING

Experiments with small microcosms have been useful in showing some of the abstract general patterns of succession, climax, population structure, and biogeochemical cycling that are observed in larger natural ecosystems. Because of their small size they could be replicated and manipulated in controlled experiments at the ecosystem level of study (Odum and Hoskin, 1957; Beyers 1962, 1963a, 1963b).

A logical continuation was the culture of somewhat larger experimental ecosystems in concrete tanks so that some of the larger-scale processes might be included such as larger animals, larger genetic reservoirs, water current systems, natural lighting fields, larger geochemical reservoirs, and sea-air exchanges. Such larger microcosms may serve as simulators of the expansive natural systems where enough of the dominant organisms and controlling processes can become established. The culture of ecosystems thus may provide means for study and eventual management of larger ecosystems. For example, can species of commercial interest be most simply managed by culturing the ecosystem in which they are dominant?

In a previous commentary (Odum, 1962), ecological engineering was defined as environmental manipulations by man using small amounts of supplementary energy to control systems in which the main energy drives are still coming from natural sources. Formulae for ecological engineering may begin with natural ecosystems as a point of departure, but the new ecosystems which develop may differ somewhat since boundary conditions established in the engineering process are different.

Thus attempts to culture some marine ecosystems in ponds are also experiments in ecological engineering of new systems because of such special conditions as pumped circulation, tank walls, constant salinity, and diminished immigration from larger population reservoirs.

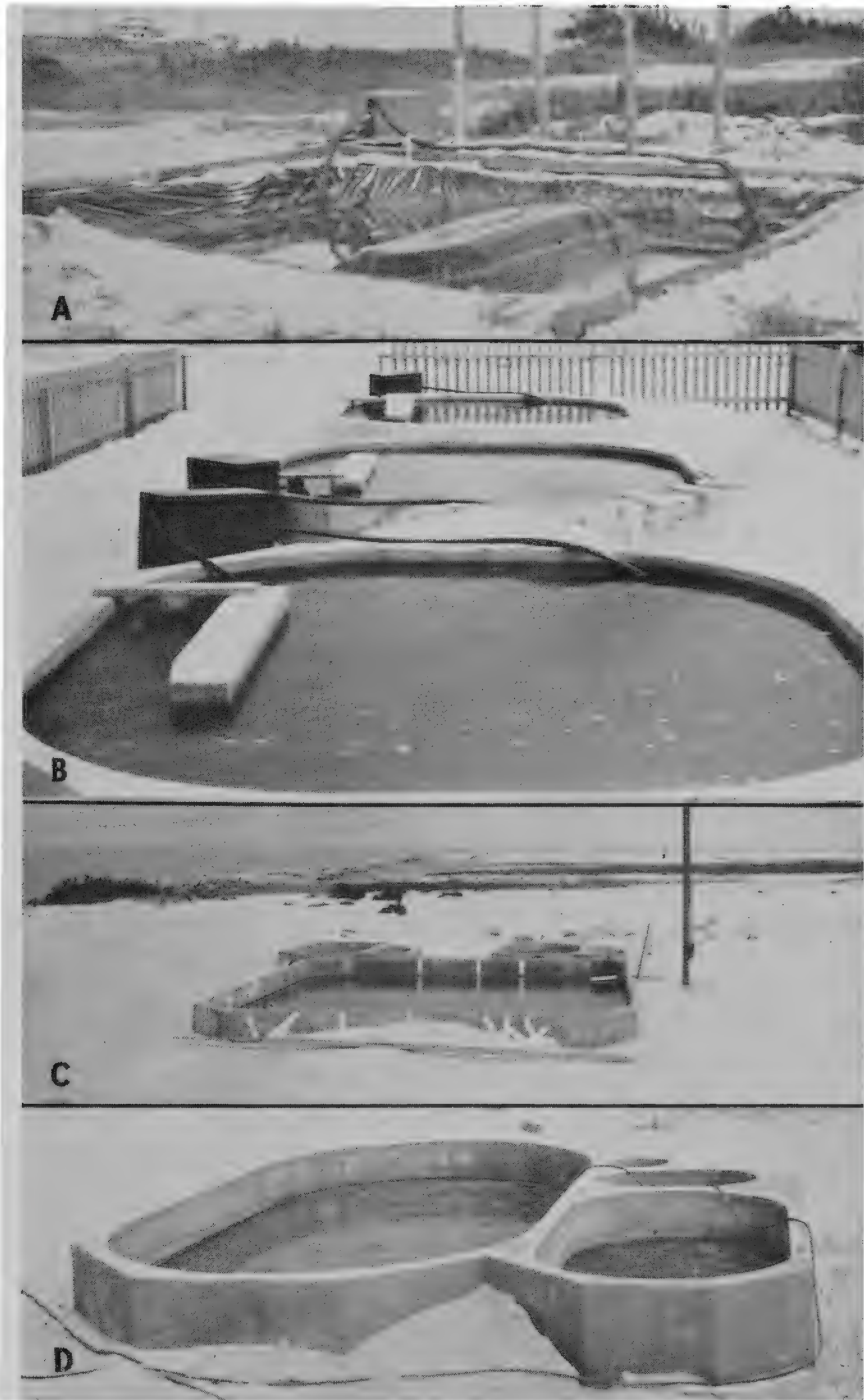


FIG. 1.
A. Plastic oyster reef pond system with island and circulatory pump.
B. Triplicate reef ponds in concrete.
C. Grass Pond.
D. Blue-green mat ponds.

Methods

MEASUREMENTS

Diurnal curve methods for study of photosynthesis and respiration were followed as described in other papers on oxygen (Odum and Hoskin, 1958; Odum and Wilson, 1962); on pH-CO₂ (Beyers and Odum, 1959; Beyers, *et al.*, 1963). Diurnal curves were very uniform and regular without the complication of diurnally varying current velocities found so often in field measurements. However, reaeration constants in the reef ponds were a function of the stirring rates in the ponds with pumps.

Reaeration constants for the plastic pond and the grass pond were estimated from the graphs on the limiting premise of constant nighttime respiration. This older procedure overestimates the diffusion constant because it includes any change in nighttime respiration rates as part of changes in reaeration rate.

In the triplicate reef ponds an experiment was conducted to infer the reaeration constant comparing a plastic covered pond with one not covered as reported in Fig. 2. Following a winter shut-down period, new oysters and other reef components were added and the ponds interpumped for two days. After ponds were again isolated on May 3–4, a heavy polyethylene translucent sheet was placed on top of the surface of pond number 1 with less than 1% of the water surface exposed to air. Pond 2 was left uncovered. Evidence that the oxygen patterns of the ponds were similar was obtained May 6–7 with both ponds uncovered. Since insolation was less that day as indicated by the pyrhelimeter the May 6–7 data are not a perfect control on the plastic experiment May 3–4.

The two May 3–4 diurnal oxygen curves (covered and uncovered) were plotted together for comparison (Fig. 2). The rates of oxygen decrease at night were greater in the covered pond. The difference between the rates of night decline in the two ponds divided by the saturation deficits provided a reaeration coefficient that was used for computing oxygen metabolism values in these ponds (0.5g O₂/m³/hr at 100% deficit). That this coefficient led to oxygen data in agreement with pH-CO₂ method with a nighttime RQ of 0.7 to 1.1 was a check on the approximate accuracy of the reaeration constant used. Rate of change graphs corrected with this constant show a decline of respiration between sunset and sunrise as already studied extensively by Beyers (1963a, 1963b) in other systems. When the constant respiration assumption is made in the old procedure, a reaeration constant between 1 and 2 g oxygen per m³ results. As discussed elsewhere (Odum, Beyers and Armstrong, 1963) the respiration decline at night is expected to be maximal in a system like that of the reef ponds in which nanoplankton are important and less important in systems with more plant storage capacity for labile new photosynthetic products like the benthic systems including the grass pond and the blue-green mats.

For the shallow blue-green mat ponds, a reaeration constant of 1 g/m³/hr at 100% deficit was used based on studies of other shallow environments with benthic communities (Odum and Wilson, 1962).

Application of the Ohle (1953) test for Winkler interference was made in the ponds with results similar to findings in the bays. Winkler results were not more than a few tenths of a mg/l off in aerobic conditions, but larger errors 1 mg/l or more developed during the low oxygen periods late at night. Thus, as indicated in Table 1, Ohle correc-

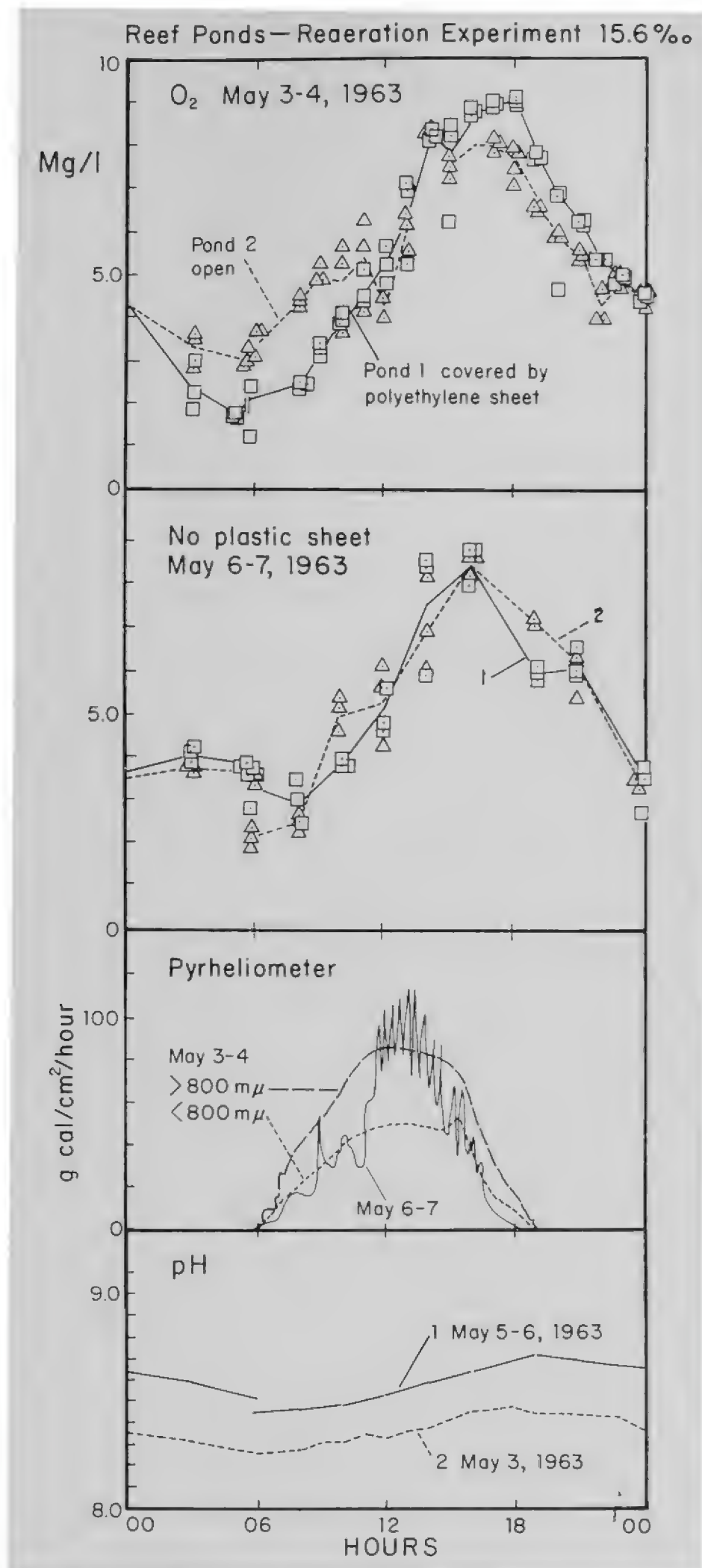


FIG. 2. Comparison of diurnal oxygen graphs in interpumped triplicate ponds with and without plastic sheets restricting reaeration, May 3-6, 1963. pH records are for uncovered ponds. The diurnal records of total insolation were made by an Eppley pyrheliometer and the visible fraction computed by subtracting the values when covered by an RG-8 Schott filter which transmits in the infra-red.

TABLE 1
Ohle Analyses

			1 Winkler	2 Winkler Plus Ohle	3 Ohle only	4 Corrected (2-3)	5 Anomaly (1-4)
Reef Pond, Sept. 12, 1962	Pond 1	0600	0	2.72	1.99		
			0	2.60	1.44		
			0	2.65	1.98		
	Pond 2	1830	0	2.66	1.80	.86	— .86
			11.37	14.21	2.55		
			11.37	14.11	2.52		
	Pond 1	1500	11.47	14.06	2.55		
			11.40	14.13	2.54	11.59	— 0.19
			14.14	13.92	0.17		
Mat Pond, Sept. 4, 1962	Pond 1	1845	13.49	14.95	0.28		
			13.81	14.44	0.22	14.22	— 0.41
			7.38	9.02	0.08		
	Pond 2	0540	7.33	8.82	0.14		
			7.35	8.92	0.11	8.81	— 1.46
			0.0	0.28	0.0		
Mat Pond, Sept. 3, 1962	Pond 1	1900	0.0	0.59	0.0		
			0.0	0.44	0.0		
			6.93	3.42	1.35		
Blue-green Mat Transplanted to Laboratory Cylinder, Sept. 5, 1962		0600	2.88	4.24	1.13		
			4.90	3.83	1.24	2.59	— 2.31
			12.4	14.4	1.03		
Sept. 5, 1962		1800	10.6	12.2	1.80		
			11.50	13.3	1.41	11.89	— 0.39
			9.20	11.10	0.0		
			14.70	18.10	1.35		
			12.40	15.40	2.39		
			12.1	14.9	1.25	13.65	— 1.55

tions are required in the night periods. That this occurs in fertile marine systems without pollution is of considerable interest. Since metabolic rates are computed as changes, the effect on computations of rates becomes significant mainly in the computation which corrects for reaeration. In this paper the original Winkler analyses are shown and the Ohle correction also indicated where known, but the metabolic rates are made with an Ohle correction. Further evidence for a diurnal change in Winkler interference is provided in a paper on abnormal bays (Odum, *et al.*, 1963).

Since the pH-CO₂ method involves neither reaeration correction nor interference correction comparison of the metabolic results of the two methods concurrently are important. Metabolic quotients are computed where data are available (Table 2).

Gross photosynthesis and 24 hour respiration rates are related on a molar basis (CO₂/O₂). As indicated in the several examples in the figures, a slanted straight line is drawn from pre-dawn respiration to post-sunset respiration for this purpose.

The Mancy-Okun lead-silver membrane electrode for oxygen was used in the systems with non-aerobic conditions to show the presence of some oxygen and confirm the interference with the Winkler analyses indicating zero at that time. Phosphorus measure-

TABLE 2
Metabolism, Metabolic Quotients, and Efficiencies of Gross Production based on
50% of pyrhelimeter records.

	Pond number	Oxygen g/m ² /day		Carbon g/m ² /day		Metabolic quotient CO ₂ /O ₂		Efficiency O ₂ × 4.5
		P	R	P	R	AQ	RQ	% of visible
Reef Ponds (See also Fig. 6)								
March 23-25, 1962	1	9.3	11.5	2.8	3.1	0.80	0.72	2.1
	2	12.5	11.4	....	....	....	....	2.3
	3	16.7	14.6	....	....	....	....	3.3
March 25-26, 1962	1	....	....	1.9	2.8	....	....	....
March 26, 1962	1	....	....	1.6	1.7	....	....	....
April 18-19, 1962	1	5.8	11.6	....	....	....	....	0.9
June 7-8, 1962	11	6.9	6.8	....	....	....	....	1.0
	2	0.4	10.8	....	....	....	....	1.6
	3	6.7	7.3	....	....	....	....	1.0
July 19-20, 1962	1	7.7	12.2	....	....	....	....	1.4
	2	5.8	8.7	2.6	2.5	1.22	0.78	1.0
	3	6.6	9.6	....	....	....	....	1.2
August 8-8, 1962	1	7.8	9.5	....	....	....	....	0.8
	2	8.9	10.7	3.8	3.5	1.1	0.88	0.9
	3	5.8	10.0	....	....	....	....	0.6
Sept. 11-12, 1962	1	13.7	13.7	....	....	....	....	2.2
	2	15.2	19.2	....	....	....	....	2.4
	3	4.7	9.5	....	....	....	....	0.7
Sept. 12-13, 1962								
½ covered with plastic	1	14.0	17.0	....	....	....	....	2.2
Uncovered	2	13.2	14.1	....	....	....	....	2.3
May 3-4, 1963								
With plastic cover	1	6.6	7.4	....	....	....	....	0.7
Uncovered	2	5.1	5.8	2.2	2.0	1.2	0.7	0.6
May 6-7, 1963	1	5.1	7.1	2.5	2.4	1.7	1.1	1.05
	2	5.1	4.8	....	....	....	....	1.05
Grass Pond (Also see Fig. 11)								
June 8, 1961		3.3	4.8	1.7	1.9	1.3	1.06	0.5
June 15-16, 1961		2.8	3.8	1.2	0.72	1.1	0.5	0.7
July 12-13, 1961		4.8	3.8	4.0	1.5	2.2	1.0	0.6
Blue-green Mat Pond								
July 3-4, 1962		5.2	5.4	5.2	5.2	2.7	2.5	0.5
July 22-23, 1962		....	....	1.3	1.3	....	....	....
Aug. 6-7, 1962		....	....	12.3	12.0	....	....	....
Plastic Pond (See also Fig. 4)								
Nov. 6, 1960		1.5	0.1	1.2	0.7	2.1	1.9	....

ments were made with perchloric acid digestions following Zwicker and Robinson (1944). Iron analyses were made by Miss Lorna McGough and Dr. Patrick Parker using the phenanthroline method of Lewis and Goldberg (1954). Alkalinites were titrated with dilute HCl to an end point of pH 5.0 indicated with a glass electrode.

Except during August, 1961, and August, 1962, continuous recordings with a 50 junction Eppley pyrhelimeter were taken using an amperometric recorder of Yellow Springs Instrument Co. Calibration was made using the electrical voltage equivalent of radiant energy supplied by the Eppley Co. and by means of amperage measurements with a Weston-calibrated microammeter. To obtain the fraction available to photosynthesis, the pyrhelimeter was covered with a box made of RG-8 Schott filters which excluded the visible rays available for photosynthesis but transmitted the infra-red rays not usable in photosynthesis. The difference between the two was taken as available energy for primary production. See the example in Fig. 2. To compute efficiency where the filter was not used, visible light was taken as 50% of total pyrhelimeter record.

In much of the field work reported in previous papers, a hand light meter with an

approximate foot-candle scale provided by the manufacturer was used (General Electric Golden Crown Exposure Meter, Type PR3, with an incident light attachment). The ease of use, sensitivity, portability, and low cost made the meter useful in the field. Whereas it is not possible to convert approximate foot-candle data to energetic data without detailed analysis of the spectral composition, in practice where there are some similarities in spectral composition of incident insolation it may be possible to obtain some empirical relations between the foot-candle data and the pyrliometer data for some representative sunny conditions such as clear sky and broken cumulus. Foot-candle and pyrliometer graphs were plotted as overlays in several diurnal graphs in this paper. A graph of foot-candle estimates with the GE meter is plotted as a function of pyrliometer readings in Fig. 3. This graph provides a rough method for converting one type of data to the other where only one was available in similar circumstances in the south Texas area. The abscissa is 50% of total insolation so that foot-candle estimates can be converted to available energy for photosynthesis. The dashed line is extremely

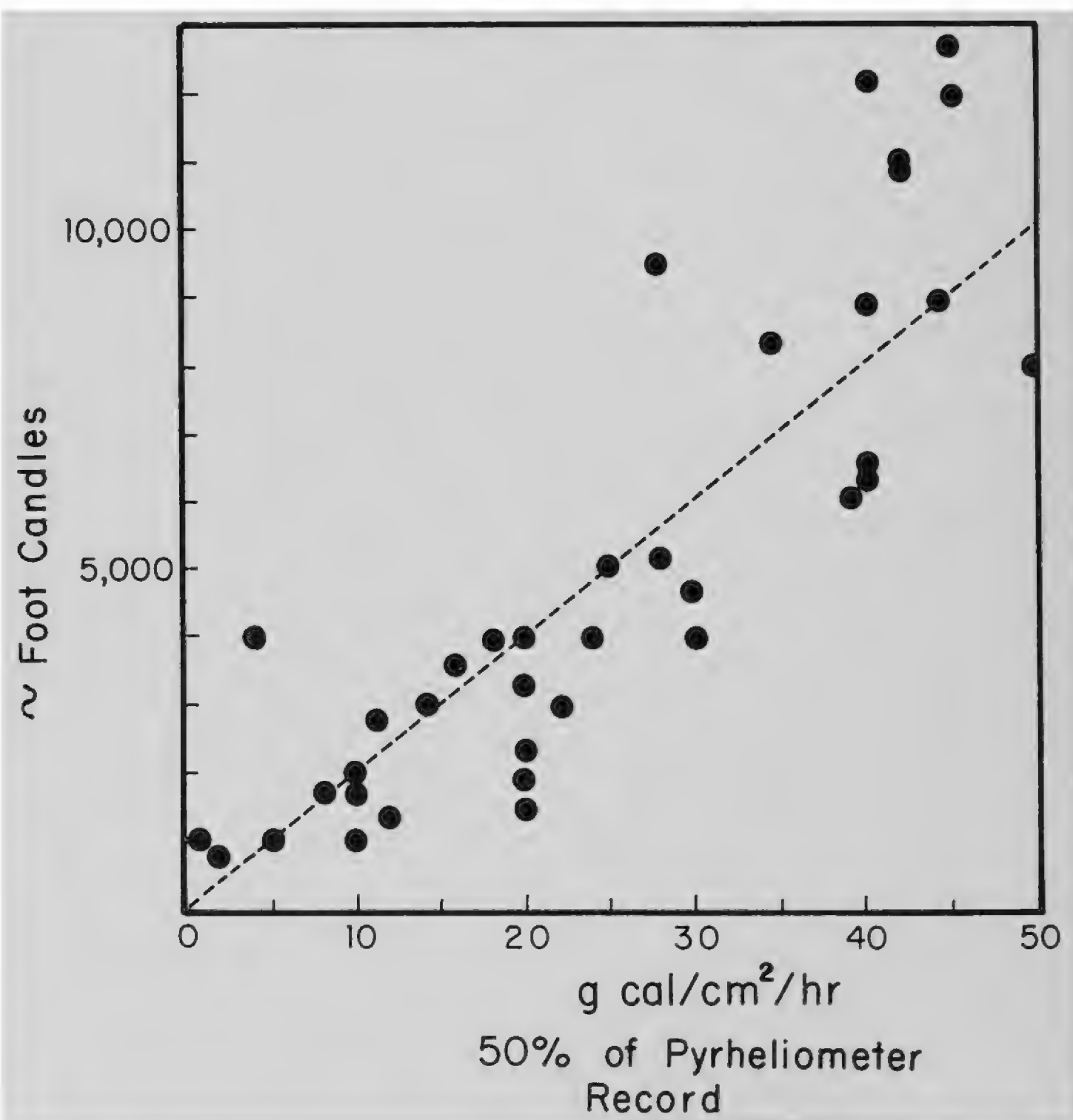


FIG. 3. Graph of foot candles from a General Electric hand exposure meter as a function of 50% of the total radiation from an Eppley Pyrliometer.

approximate. Use of the Schott filter indicated that percentages of total insolation in the visible were from 45 to 80% depending on clouds.

Total organic matter in water samples, and the organic matter in millipore filtrates were analyzed according to the persulfate digestion and infra-red CO_2 method of Wilson (1962).

After the experience with cracking of the large pond in Hurricane Carla, later ponds were constructed with enough reinforced steel and basic foundations on creosote pilings jettied 12 feet into the sand to prevent damage from undermining of the sand by hurricane waves and currents.

DIURNAL SAMPLING BUOY

With the help of Dr. Marcel Gres and Tracor, Inc., of Austin, Texas, a floating fiberglass buoy was developed for filling 125 cc glass stoppered bottles over a 24 hour period. A timing motor operating from a storage battery operated a solenoid valve and a selector switch allowed the bottles to fill every three hours by gravity fill. Originally, the buoy was designed to take samples for later measurement of oxygen and pH, but no satisfactory method was found for preservation since all of the preservatives and poisons yet tested either changed oxygen contents or interfered with the Winkler method. Curves which duplicated those in the outside water were obtained only in turtle grass beds in which the plankton was negligible and the waters entering the buoy were thus effectively removed from the metabolism of the community. Although designed with a chamber for ice, tests of the buoy operating with ice indicated inadequate preservation. The mechanical system of the buoy was found to work adequately in the experimental ponds, and the buoy may become useful with diurnal sampling studies involving sampling for radio-tracers and other chemical entities not subject to metabolic change while in the bottles. Tracor Corp. manufactured the buoy for \$800.

PONDS AND SEEDING SEQUENCES

With the reasoning applied in the microcosm studies, organic biomass and essential inorganic constituents were transferred from the environmental prototype to the tank so that the release of chemicals from respiration and decomposition would provide the inorganic ratios most suitable for the plants of that system and inversely so that the plant species thus competing with that inorganic composition would have the proper nutritive ratio for the consumers normally in that system. Then the dominant boundary conditions of the prototype were set with respect to water depth, circulation rate, and sediment type. Finally species from the prototype environment were added in quantity and diversity including micro-organisms, plankton, benthic animals, and small fishes. Where replications were desired, ponds were intermixed with inter-pond pumping. The ecosystems which emerged in a few days were the result of organizational influences such as natural selection and behavioral responses of species within the system. A moderately large metabolic rate resulted in each of the experimental sequences.

Plastic Reef Pond. In July, 1960, a pond ecosystem simulating a low salinity bay was improvised by laying a black sheet of polyethylene in an excavation in the sand 4.9 by 5.1 m as shown in Fig. 1A. A small island was arranged at one end, and a live oyster reef from San Antonio Bay was introduced into the narrow channel 0.6 m wide made by the island. A pump was arranged to draw water from the broad part of the pond discharging across the reef at about 0.2 m/sec. Thus the pond water was being

moved from bay area to reef simulating bay-reef relations of the oligohaline Texas bays. In several diurnal curves, oxygen sampling was done just above and below the rapid current zone of the reef and the values reported separately (Fig. 5). Fresh water was added to balance evaporation. The area of reef to total photosynthetic surface was 1 to 20 like that in a diagram for the Copano Bay area given by Hedgpeth (1954). Twenty-eight grams of nitrogen and phosphorus fertilizer were added. There were immediate blooms of diatoms with a rich brown color. Then the patterns were followed through the summer and during the fall. In this period, there were interruptions due to heavy rain-floods which overran the pond decreasing the salinity and covering the pond bottom with sand and sediments from outside. In this pattern of events, conditions in the upper bays were simulated.

After one such flooding all the oysters were killed and replaced. It was obvious during the fall experiments that the plastic had been punctured, and the pond was in exchange with the ground water. At the end of the experiment, the system was allowed to become entirely fresh.

Triplicate Reef Ponds in Concrete. In the fall of 1961, the arrangement for the reef-

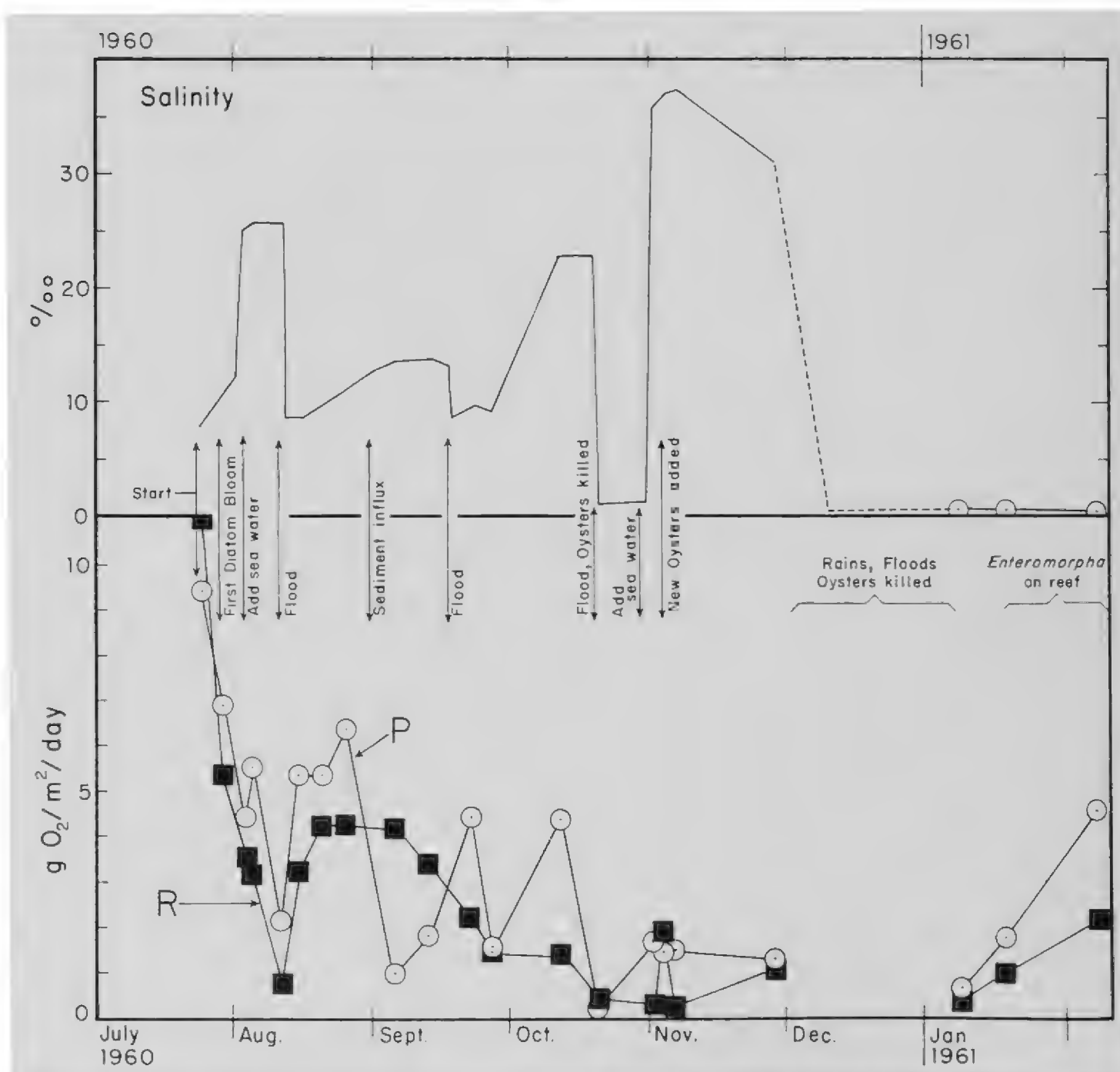


FIG. 4. Seasonal graph of salinity, metabolism, and the sequence of events in the plastic oyster-reef pond system (Fig. 1A).

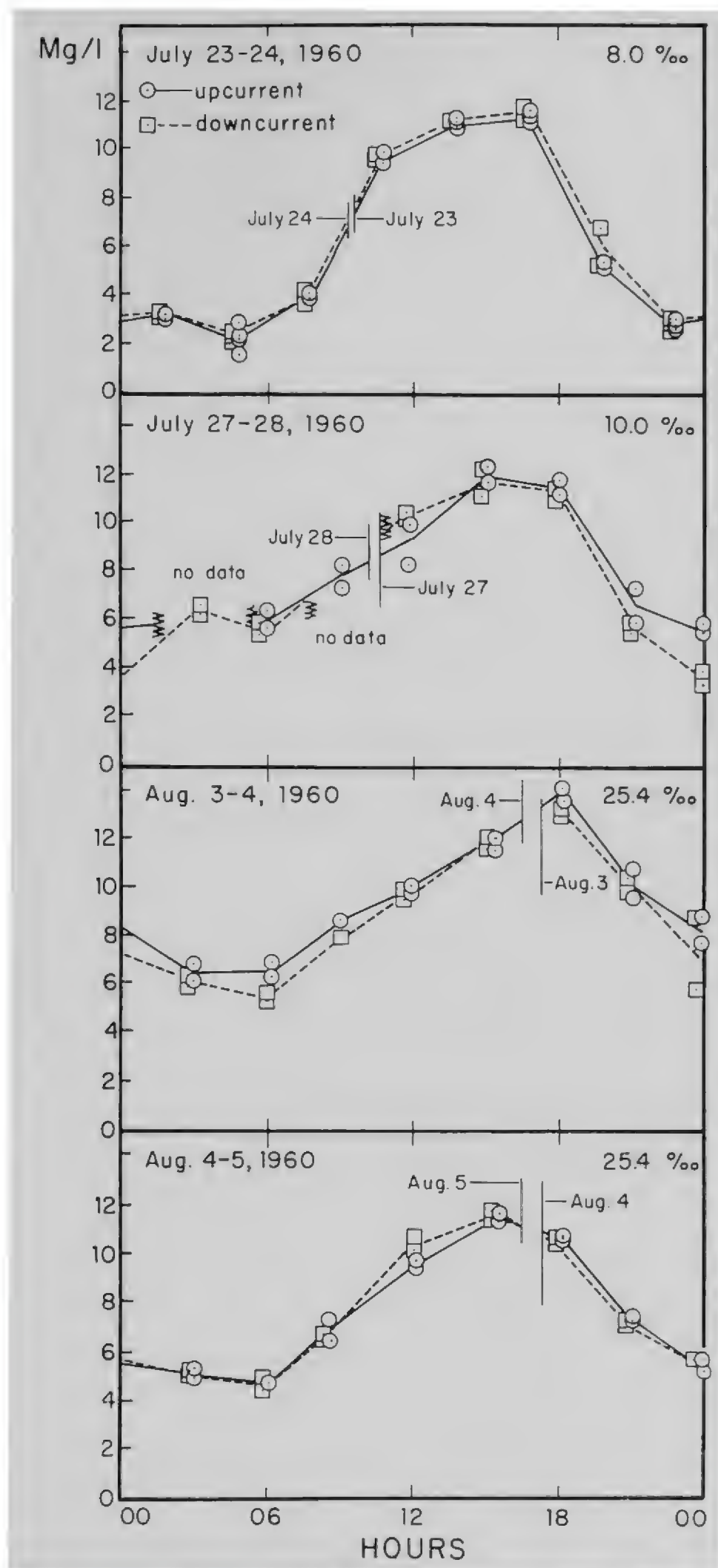


FIG. 5. Four diurnal curves of oxygen in the plastic oyster reef systems. Measurements were made upstream and downstream from the reef assemblage.

island-bay plankton system in the plastic pond was constructed in triplicate in concrete as shown in Fig. 1B. Sea water, sediment, and reef materials were introduced and seeded as before. Depth was adjusted to 0.52 m and salinity to about 16 ‰. The area of water in each pond was 11.4 m² and the volume was 5.87 m³. The three ponds were homogenized by interconnecting intake and discharge hoses of the 3 pumps. Then the pumps were returned to their single pond function of circulating water from the broad area to the reef. Metabolic patterns were compared between the three ponds. In setting up the three ponds the first time 5 pounds of nitrogen and phosphorous fertilizer was added on March 19, 1962, (6% N, 12% P₂O₅, 6% K, Wonder Gro Fertilizer Co., San Antonio, Texas). Very heavy nanoplankton blooms were sustained and anemones, gammarids, mud crabs, barnacles, and other animals on the reef became very numerous. Few oysters survived, however; rotifers dominated the zooplankton. After a period of 6 weeks without intermixing, differences became noticeable in the ponds. Interpumping was continued every few weeks. Later in the summer when the pumps became fouled so that circulation stopped, some stratification and the excess of respiration over photosynthesis produced an almost anaerobic nighttime condition. Then when the pumps were returned to adequate function, the ecosystems continued to maintain a near anaerobic nighttime phase. With declining light in the fall, metabolism in the pond and densities of animals on the reef declined also.

Salinities were adjusted by adding tap water to balance evaporation to a mark previously established on the wall. The alkalinity of the tap water used was 2.1 milliequivalents per liter on May 5, 1962, this water being derived from Corpus Christi water mains and ultimately the dam on the Nueces River. A study of alkalinities was made in these ponds under the arrangement of adding high alkalinity fresh water to balance evaporation.

Twice in May after sediments were added, carbon dioxide gas from a tank was injected for several hours into the pump intake lowering the pH. The carbon dioxide bubbles entering the pump were completely dissolved in passing through the pump system.

A diurnal study of total and filtered organic matter was made by Ronald Wilson on March 24, 1962.

For economy reasons, the interchangeable pump units in these experiments were 1/3 horsepower "Mitey Mites" with the disadvantage of a bronze impeller which undoubtedly contributed copper to the systems. Discharge rates were 62.5, 63.4, and 60.9 liters per minute on May 7, 1963.

Grass Pond. In the spring of 1961, a concrete pond 13 m by 11 m and 1.3 m deep was constructed with rounded corners as shown in Fig. 1C. In early June turf of turtle grass bottom and associated animals and sediments were brought from Redfish Bay covering the bottom with grass beds in many places and with a layer of sediment throughout. Water to a depth of 0.4 meters was pumped from the inlet nearby. Thereafter, tap water was added as needed to balance evaporation to a mark thus simulating a similar process in the bays where addition of river water tends to balance evaporation. Plankton seeding was continued from many bays during the month. The pond was seined during the month and components of the nekton smaller than about 4 inches were allowed to remain. Diurnal curves of metabolism were taken with oxygen and pH-CO₂ methods. Class projects were done on the ecosystem, including a study of foraminifera by Warren Horton and attached diatoms by Alice E. Sharp. Diurnal measurements of a number of variables were

made. The effectiveness of mixing under wind stress was studied with duplicate oxygen and temperature measurements. Studies were terminated by Hurricane Carla which flooded and broke the tank September 9, 1961. The cracks have since been repaired and the system is again in use.

Blue-Green Algal Mat Ponds. In spring, 1962, additional small concrete ponds were built as shown in Fig. 1D. The bottom was covered with a layer of sand. Then on June 28, 1962, partially dry, leathery blue-green algal mats from heavy beds near a bleed-water outfall in the Laguna Madre 3 miles south of the Flour Bluff Causeway Toll Station were collected, stacked, and transported in a station wagon like sheets of burlap. The mats had *Microcoleus*, *Lyngbya* and other genera as interwoven filaments.

These mats were placed over 90% of the bottom sands of the ponds. Sea water was added to a depth of about 10 cm simulating the conditions on the blue-green flats. Thereafter the water levels were allowed to rise and fall with rain and evaporation. Diurnal measurements were made for comparison with similar measurements in the blue-green mat systems of the bays such as reported by Odum, Cuzon, Beyers, and Allbaugh (1963).

Results

Metabolic rates for all pond experiments are given either in the tables or in the seasonal graphs.

REEF POND SYSTEMS

The sequences of salinities, metabolism, and events are given for the plastic pond experiment in Figs. 4 and 5, and for the triplicate concrete ponds in Figs. 6–10.

Plastic Reef Pond. The system was exposed to an alternating sequence of sharp salinity changes like that in the bay prototype. The graph (Fig. 4) shows a rapid recovery of community metabolism following salinity shocks even when the salinity changes caused death of the oysters and other dominant populations as on August 11 and October 20. The ability of the system to substitute new populations with little interruption of photosynthesis or respiration was also noted in field measurements in Nueces Bay (Odum *et al.*, 1963). The decline of metabolism during the latter part of the season accompanied decline in insolation and resembled the decline in metabolism in the bays. The slight metabolism on August 11–12 was associated with heavy rain clouds during the day. The evaporation rate was 8 to 12 cm per week. Daily temperature sequences ranged from 28°C at dawn to 39°C before sunset.

With the pump then being used, there was some injection of bubbles. The reaeration coefficients as determined from the diurnal curves (subject to the assumption of constant nighttime respiration) were variable, in part due to the variable effectiveness of the pump, and ranged from 0.8 to 3.0 gm oxygen per m³ per 100% deficit. The diurnal curves were all without anaerobic nighttime phases. P and R were out of phase more than in some experimental ecosystems in which irregular boundary fluctuations were eliminated (Beyers, 1963a).

A slightly different oxygen concentration was sometimes found below the reef stream compared with that above (Fig. 5) the difference representing the metabolic and reaeration roles of the reef under the adapted conditions. Possibly significant differences (paired points not overlapping) were present in two of the four graphs, (July 27–28 and August 3–4).

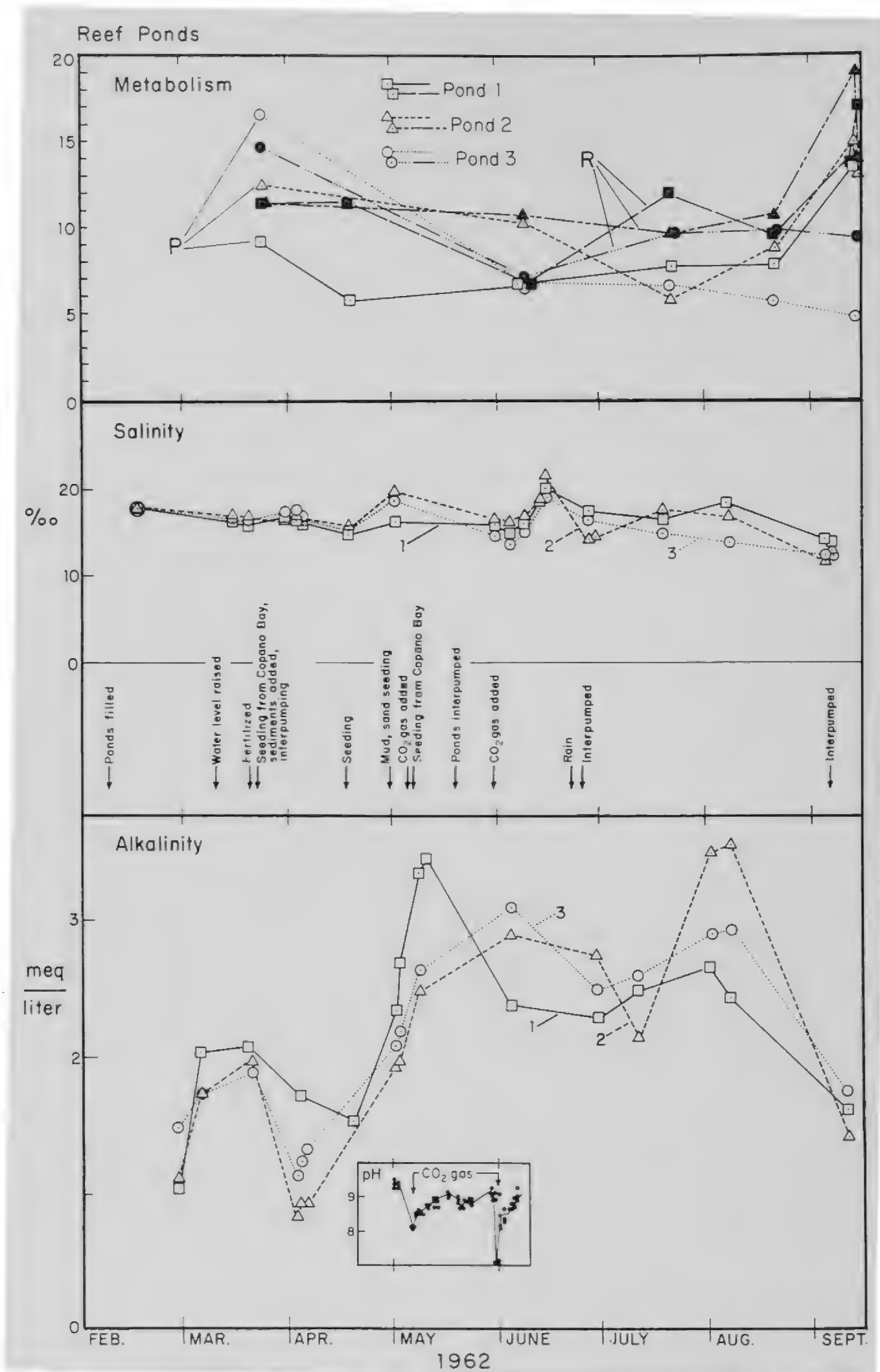


FIG. 6. Seasonal record of metabolism, salinities, alkalinities, and the sequence of events in the triplicate reef ponds in 1962. The pH record during the carbon-dioxide gas injection experiments is given as an inset.

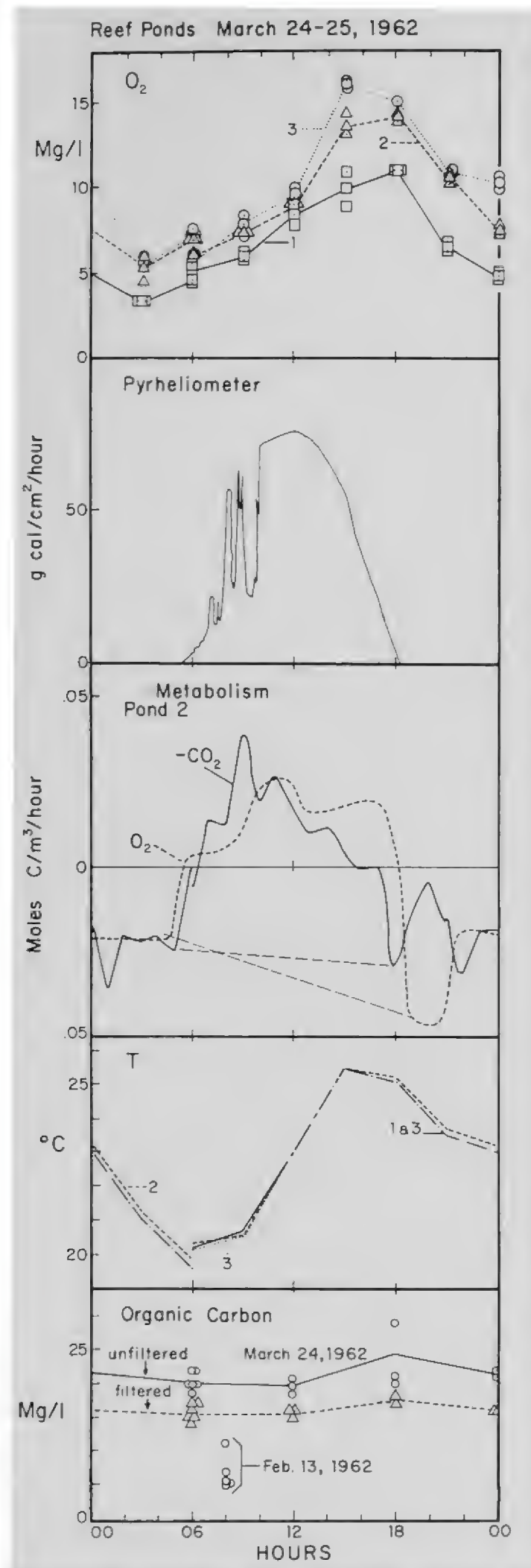


FIG. 7. Diurnal record of oxygen content, total insolation, carbon and oxygen metabolic rate, temperature, and organic carbon concentration in the triplicate reef ponds March 24-25, 1962.

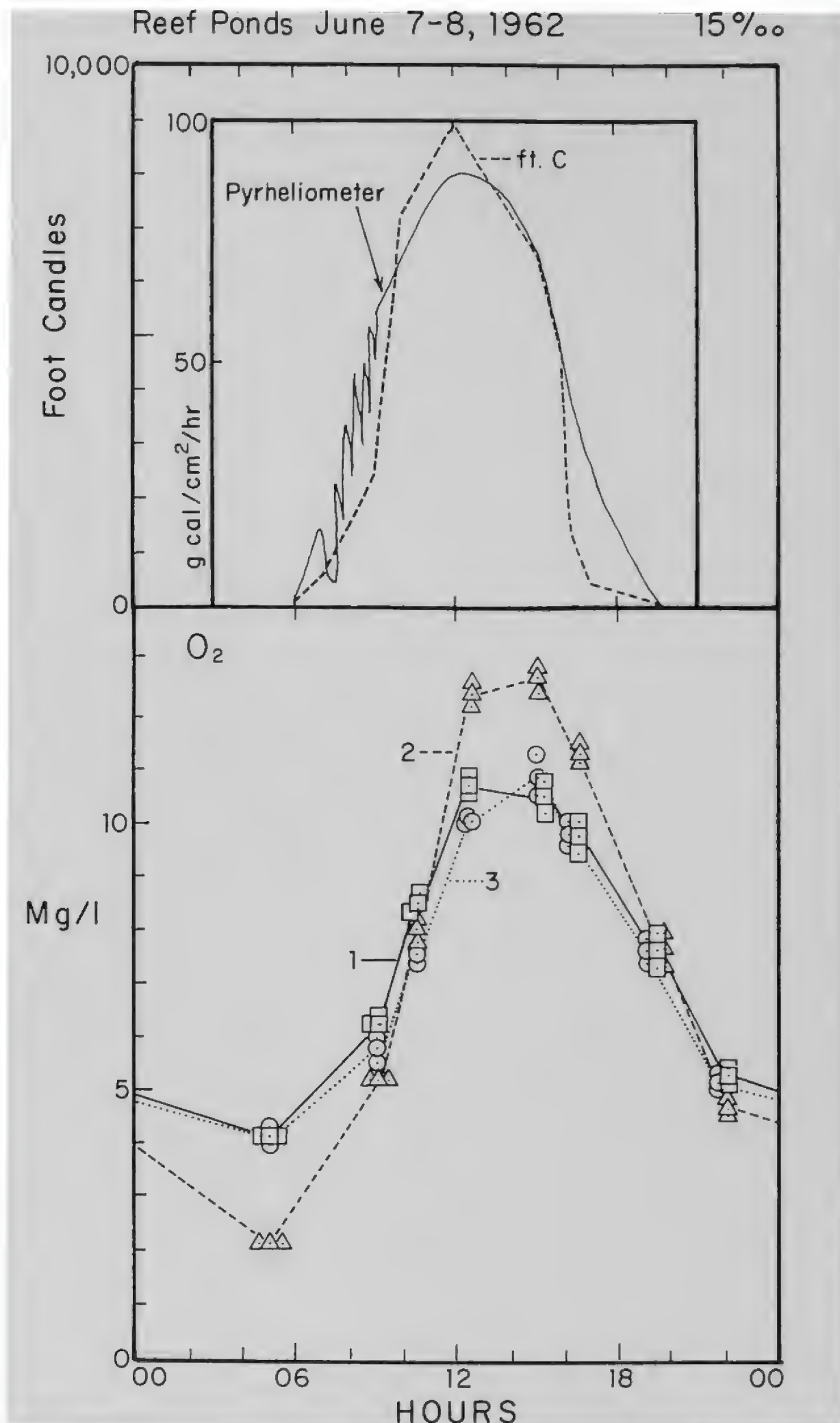


FIG. 8. Diurnal record of incoming insolation, foot candles incident, and oxygen concentrations in the three reef ponds June 7-8, 1962.

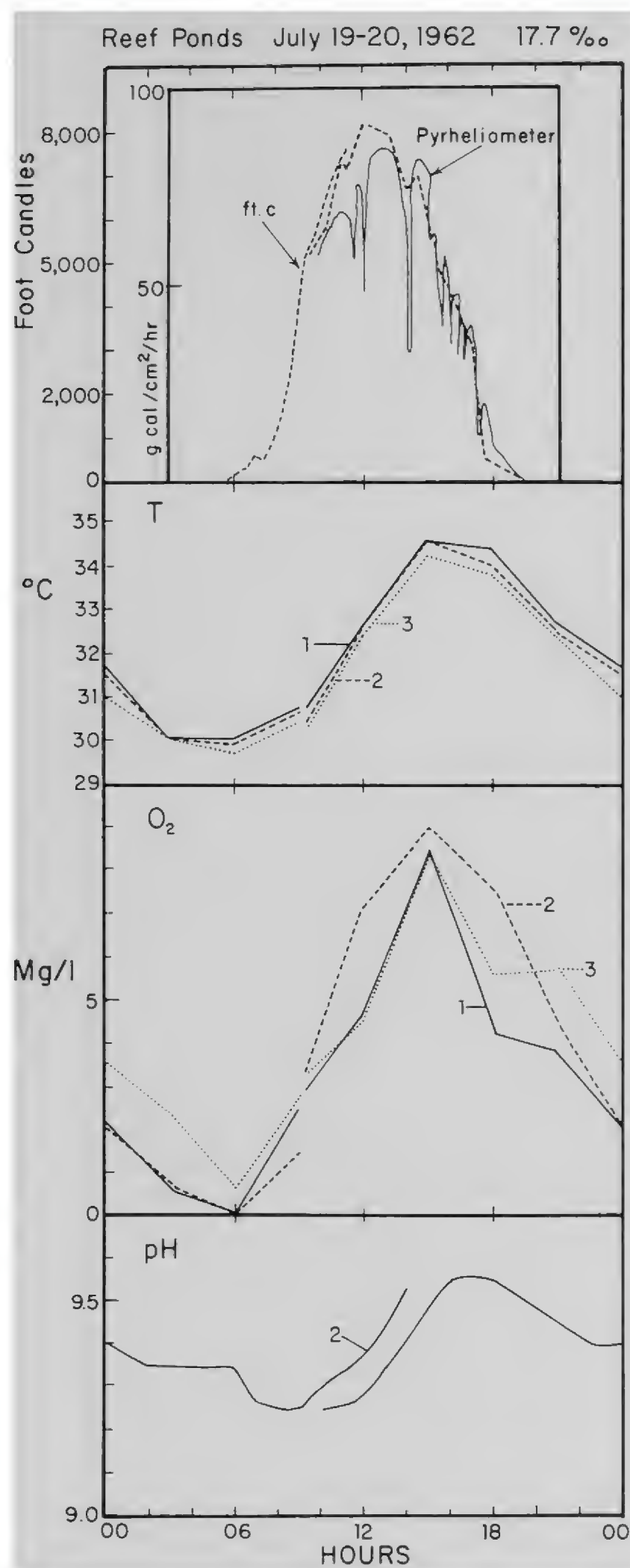


FIG. 9. Diurnal record of incoming insolation, incident foot candles, temperature, oxygen content, and pH in the triplicate reef ponds July 19-20, 1962.

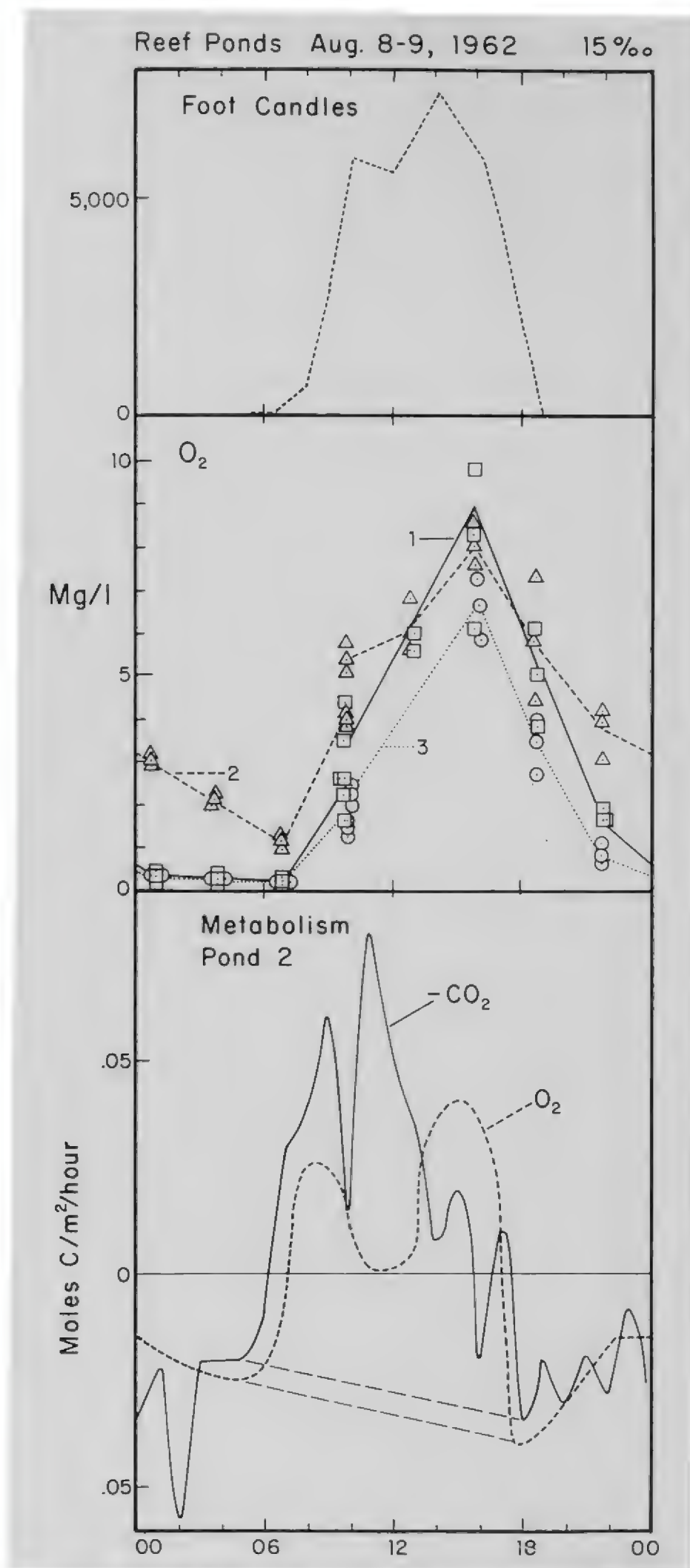


FIG. 10. Diurnal record of incident foot candles, oxygen concentration and rate of carbon and oxygen metabolism in the triplicate reef ponds August 8-9, 1962.

In the upstream and downstream data in Fig. 4, the changes in oxygen concentration range from values too small to be significant to changes of 1.0 mg/l. With a flow of 0.2 m/sec. through a reef cross sectional prism of 0.6 by 0.1 m or less, the reef metabolism ranges from 0 to 2 g/m² per hr as prorated over the 22m² of the total bay-reef system. Thus the reef at times may have had a metabolic rate dominating the total metabolism, but at other times the metabolic contribution of the reef was minor. Some photosynthetic contribution from reef algae to the system may be detectable in these upstream-downstream curves as indicated by oxygen increases in daytime July 27-28 and August 4-5. The changes on July 23-24 suggest aeration. Large variations in the respiration of an oyster reef may be consistent with the findings of Collier (1959) that oysters pump at widely varying rates in relation to the food concentration.

On November 1, 1960, after the reef had been removed, diurnal metabolic measurements were taken in which the oxygen ranged from 90 to 150 per cent of saturation. Then, on November 2, a new reef of oysters and barnacles was placed in the island channel and another diurnal oxygen curve was taken on November 3 in which the oxygen ranged from 70 to 125 per cent. Whereas photosynthetic rates were similar (November 1, 1.4 g/m²/day; Nov. 3, 1.6 g/m²/day) the respiration rates increased from 0.3 g/m²/day on Nov. 1 to 1.9 g/m²/day on Nov. 3. However, a low respiration rate of 0.3 g/m²/day was obtained again on Nov. 6.

At peak population the reef held 123 *Crassostrea virginica*, 410 *Brachiodontes exusta*, 36 small mud crabs, and many *Balanus eburneus* and bryozoa. The spectacular diatom bloom contained numbers up to 1300 *Pleurosigma* sp. and *Amphora* sp. per square millimeter of bottom ooze. The same species were present in six oyster stomachs in concentrations 9 to 10 times greater than outside. Although the water remained relatively clear, diatoms were being transported from their prevalent position on the bottom ooze of the system to the stomachs of the reef organisms via the current system. Increases in the brown blooms were observed after each influx of fresh or salt water.

On the evening of August 10 a large number of the heteronereis form of *Nereis dumerlii* was found swarming on the water surface of the tank, the congregation lasting 2 hours.

Triplicate Reef Ponds. The results of the salinity, alkalinity, and circulation manipulations are graphed in Figs. 6-10. Whereas the plastic pond experiment simulated oyster-diatom populations of the moderately fertile low salinity reef containing bay, different populations developed in the triplicate ponds resembling most the heavily enriched systems of upper Galveston Bay and Nueces Bay. Most of the oysters did not survive, but there was a very heavy reef growth of other consumers, *Balanus eburneus*, gammarids, mud crabs, and sea anemones. The extremely productive plankton was dominated by small green nanoplankters and rotifers. The swarm of small animals on the reef was very much like that observed on reefs between Corpus Christi and Nueces Bays in the same season.

In the spring and early summer the diurnal range of oxygen was within the aerobic range suitable for most larger animals (Figs. 7-8), but by the end of the summer the amplitude of oxygen range had increased so that oxygen values near zero were reached at night (Figs. 9-10). Temporary pump failures caused temporary stratifications and anaerobic nighttime bottom conditions during several days in July. When pump functions were restored, the system continued to develop near-anaerobic nighttime conditions even

with sustained mixing. This sequence demonstrated that an enriched bay could follow a succession towards an anaerobic nighttime oxygen condition where radiation and mixing conditions were sustained. Such oxygen regimes provided limits to the number and type of participating animal and plant populations. This experiment indicated that a wide oxygen range pattern once stimulated by some enrichment such as from pollution influx could be self maintaining. Recovery of ecosystems to normal patterns from bay enrichment may not be possible without flushout.

The three ponds set up in a similar manner, seeded, and then inter pumped did produce rough replicates with similar dominant plankton, animal populations, salinities and alkalinities. Replication of metabolic rates was not as good since conditions in the ponds gradually drifted apart over a several-week period. As indicated in Fig. 6, inter pumping was arranged several times during the 6-month sequence. The degree to which the replications were maintained can be observed from the graphs of ponds 1, 2, and 3. Whereas inter pumping momentarily makes the fluid uniform, the nekton, benthos, and reef components are sufficiently different to keep metabolic patterns somewhat apart.

A study was made of the alkalinity changes that accompanied the high rates of pond metabolism. In March when metabolism did not get an effective start in the bare tanks, fertilizer and a sediment floor was added, followed by tremendous blooms in which the alkalinity was lowered as pH levels became very high. What contribution alkali from new concrete was making at this time is not known. Later, as in all the concrete experiments, the walls became heavily coated with a biological encrusting layer thus making the walls similar to the bottom sediments as living biogeochemical exchange surfaces.

Then, in April, more seeding with organic matter containing muds contributed to respiration lowering pH levels somewhat. To control the alkalinity range upward and the pH range downward, an experiment was twice made with injecting carbon dioxide into the ecosystem as an ecological engineering technique. As indicated by the graph in Fig. 6, pH was immediately lowered, rising again in several days with increased alkalinity as the free carbon-dioxide added was neutralized by carbonate solution from the sediments.

During much of the summer, salinities were held fairly constant by adding the hard tap water to maintain a constant water level of 0.5 m. That little further rise in alkalinity developed indicates an equivalent deposition of calcium carbonate in the ecosystem as in the rapid growth observed in barnacles and mussels on the reef.

The increase of alkalinities over that of sea water due to the use of high alkalinity fresh water to balance evaporation apparently duplicates the situation in some Texas bays. Park, *et al.* (1958) showed the increase in alkalinity to chlorinity ratio in the bays. A series of 22 alkalinities from the Aransas Pass inlet into Baffin Bay via the Corpus Christi and Laguna Madre ranged from 2.9 milliequivalents/l at Port Aransas through values above 3.0 in the upper Laguna Madre to 4.0 in Baffin Bay (Park *et al.*, 1958). This system of high alkalinities is favorable for a regime of calcareous depositions in biological components reefs and sediments so that a steady state can develop between evaporation-inflow and losses from deposition and Gulf exchange. Thus the general carbonate geochemical patterns of the pond sequences were similar to the bay prototypes.

Wilson (1963) was able to demonstrate direct changes in organic matter in dark and light bottles containing plankton with direct organic matter determinations. The diurnal measurement sequence on March 24, 1962 (Fig. 7) suggests the diurnal pattern to be

expected although the method was not sensitive in this situation. Organic matter levels in the water on February 12, 1962, just after the ponds were started, were 5–11 mg/l, not much above that of the Gulf water used to start the ponds. By March, however, the ecosystem was maintaining levels of 19 to 30 mg/l like those in some of the isolated bays like the Laguna Madre and Baffin Bay. It may be postulated that with restricted diversities among the consumer networks, the organic levels in the pond must rise, thus stimulating micro-organism metabolism adequate to balance photosynthesis just as in the bays.

It may be suggested that there is a general inverse relation between dissolved organic matter and diversity of consumer circuits among higher organisms. The low nighttime oxygen regime favors restriction of species and increase of organic matter. In this sequence the organic matter is entirely self-generated and is not controlled by import or pollution.

The energetic input to the triplicate ponds during the summer was from two sources, the sunlight and the circulatory energy supplement supplied from man's civilization as a power supplement. In the absence of this circulatory energy, the processes of photosynthesis and respiration, each dependent on recirculation of products of one to the other, would have been limited to those circulatory mechanisms paid for from the systems own energy as with fishes, diurnally moving zooplankton, migrating dinoflagellates or pumping of reef animals. The pumping rate of 62.2 liters per minute from electrical power supplement contributed 4.2K Calories kinetic energy per square meter per day to the system as compared to 4200K Calories per m² of visible light received. If, in the absence of such circulation, the ecosystem were circulating nutrients by supporting large nekton at the herbivore and carnivore levels, the transfer of visible light energy through the trophic levels, thus concentrating power enough to provide movement independent of the medium, would result in the same order of magnitude of power for nutrient circulation. In the Laguna Madre, Hellier (1962) found a conversion of gross plant production to fish production of 0.074%.

In a number of graphs replicate Winkler analyses showed irregularities in the diurnal curve of oxygen at a time when the pump-driven reaeration was unchanging and the light fields were unchanging. These variations appeared, for example, in Figs. 2, 9, and 10. These changes observed in field work have often been attributed to wind variations affecting reaeration and differences in local trajectory, fish schools, etc. In the tanks they apparently represent large changes in the system metabolism such as might be provided by components of the reef pumping or not pumping. The rise in oxygen about midnight or before dawn observed in several curves may represent cessation or decline of some respiratory functions such as pumping.

GRASS POND

The records of metabolism and events in the grass pond are given in Figs. 11–13. Shortly after transplanting and seeding of the large pond a moderately high photosynthesis and respiration developed which was similar to that in parts of Aransas and Redfish Bays (Odum and Wilson, 1962; Odum, 1963). During the summer, animal and plant populations developed like those in the bay prototype. *Thalassia testudinum*, *Diplanthera wrightii*, and *Ruppia maritima* continued to maintain new growths. Benthic

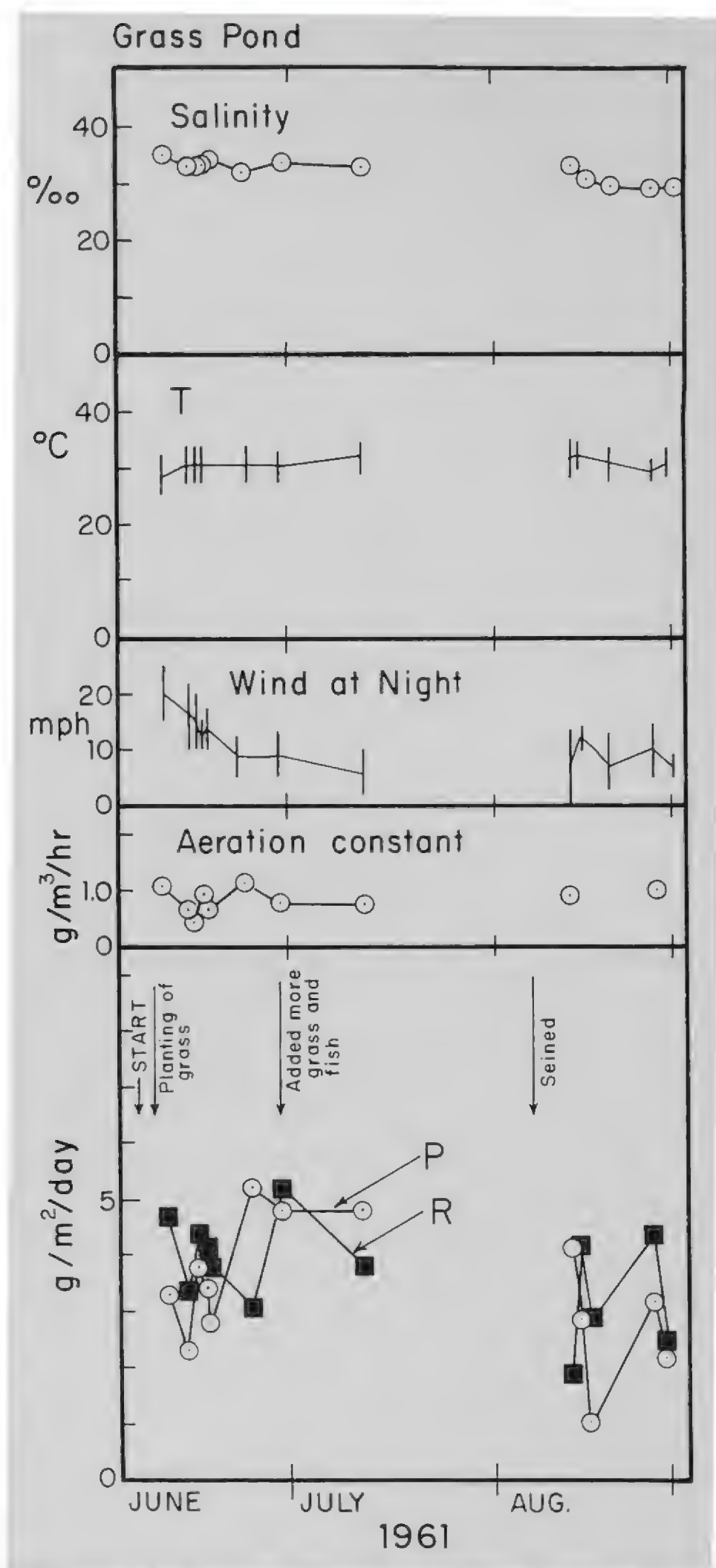


FIG. 11. Seasonal record of salinity, temperature, wind at night, reaeration constant for 100% oxygen deficit, system metabolism and the sequence of events in the grass pond.

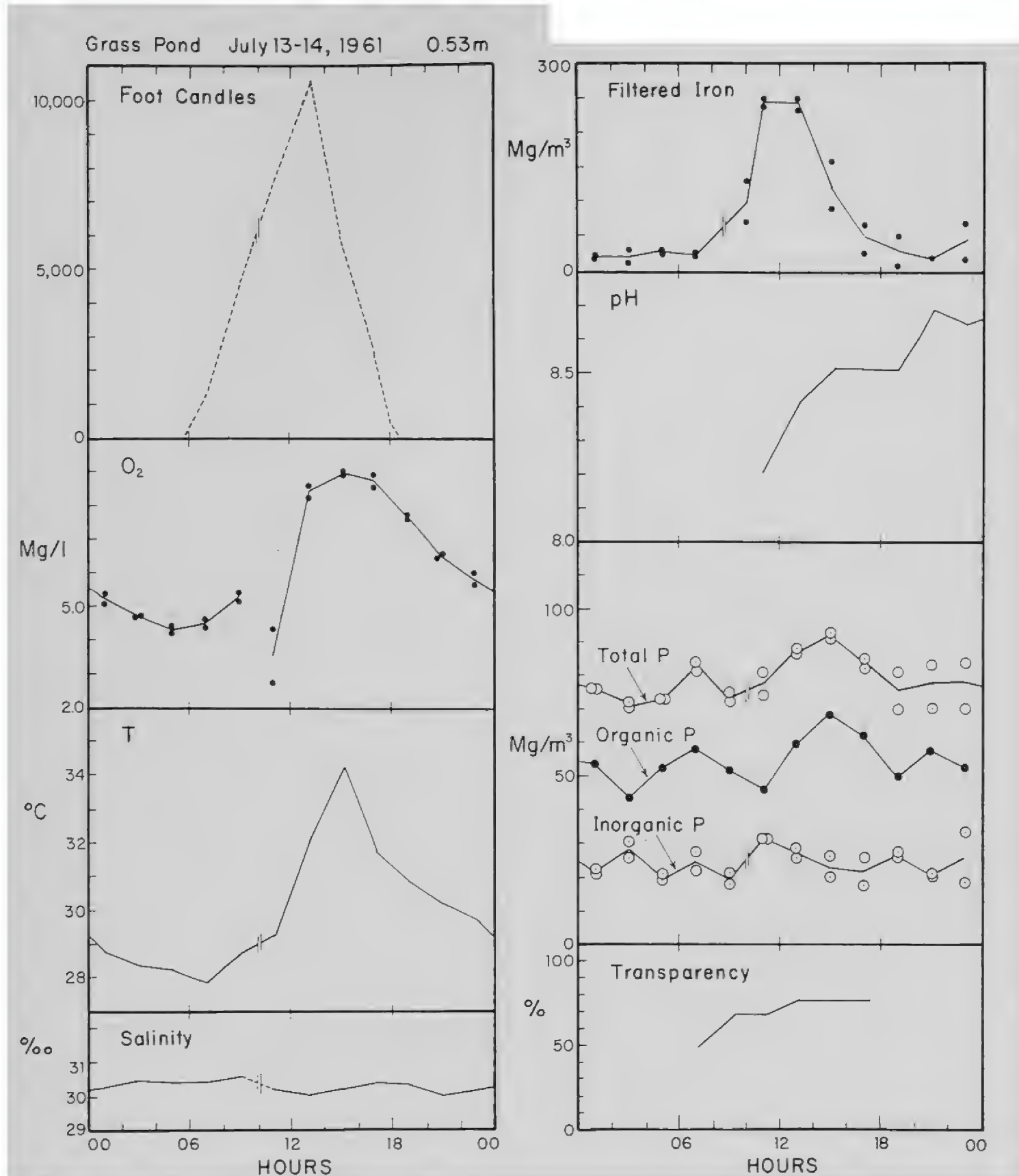


FIG. 12. Diurnal record of incident foot candles, oxygen concentration, temperature, salinity, iron in millipore-filtrates, pH, phosphorus, and bottom transparency in the grass pond, July 13-14, 1961.

diatom populations were observed in sediments and water, especially *Nitzschia closterium* and *Navicula grenville* (identified by E. J. Ferguson Wood). The dominant vertical migration of *Acartia* was verified on August 23, 1961, (Fig. 13). Brown shrimp, *Bairdiella*, *Cyprinodon variegatus*, *Fundulus similis*, and *Menidia beryllina* were common. When the pond was examined after draining on September 9, 5-inch oysters and heavy barnacle growths were observed on the walls just as on the solid substrates of the prototype bays. A dense population of bottom foraminifera was observed and studied by Wayne Horton. From his measurements of metabolism per individual with the pH-CO₂ method in vials, and from 10 bottom counts, he estimated that 5% of the total metabolism (0.030g O₂/

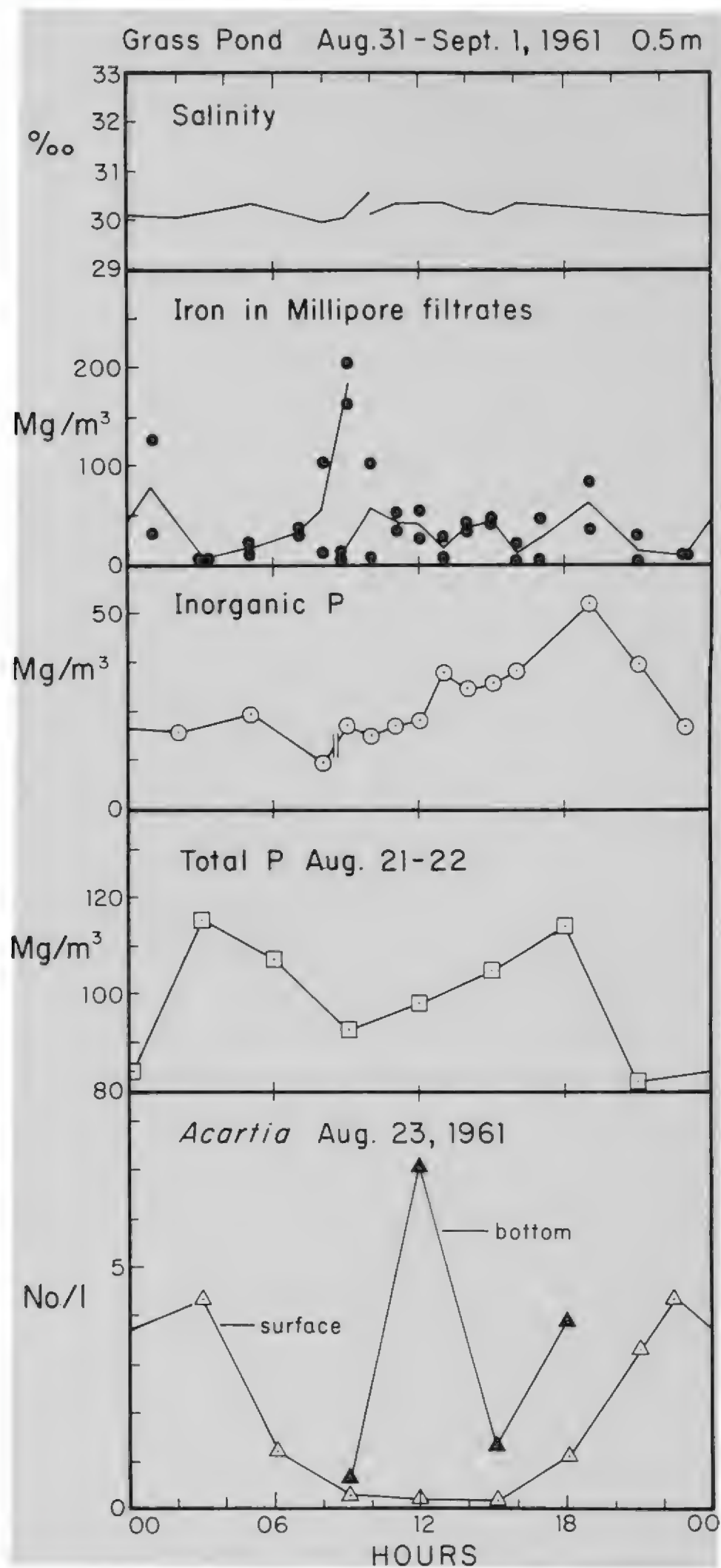


FIG. 13. Diurnal record of salinity, iron in millipore-filtrates, and inorganic phosphorus in the grass pond, August 31-September 1, 1961. Total phosphorus is given for August 21-22, 1961, and concentrations of the copepod *Acartia tonsa* are given for August 23, 1961.

m²/hr) was attributable to the dominant benthic foraminifera: *Ouinqueloculina poeyana* and *Streblus becarii*.

The diurnal variations of many properties were explored as reported in Figs. 12–13. The level of phosphorus maintained by the cycles of the ecosystem was 50 to 115 mg/m³, similar to that in the bays (Odum and Wilson, 1962). There was a curious diurnal change in water transparency conspicuous to people in the pond area even without instrumental measurements (Fig. 12). The per cent transmission to the bottom with a selenium photometer in daylight was 50% in the early morning improving to 66% by afternoon. Salinities were successfully maintained between 28 ‰ and 34 ‰ by balancing tap water against evaporation which was about 8 to 12 cm per week. The pH remained between 7.2 and 9, the temperature between 28 and 35°C, and efficiencies of gross photosynthesis between 0.5 and 1.5 per cent of visible light incident on the pyrhelimeter.

Not all of the diurnal patterns were as expected from bay studies. Although the pH rose during the day, the iron concentration of millipore filtrates increased during the day (Fig. 12), a reverse effect from that expected from considerations of pH effect on iron solubility. Phosphorus in the graphs for July 13–14 (Fig. 12) showed variation with little trend. The graphs for August 21–22 have day and night minima. The August 31 series (Fig. 13) had inorganic phosphate increasing during the day, in reverse from that expected from studies of Bruce and Hood (1959) for the bays.

One finding of considerable significance for future pond work was the demonstration of continuous mixing without stratification in the larger pond under ordinary wind stresses of the Texas coast. By having straight walls and rounded corners, no consistent vertical temperature or oxygen differences developed. The water was observed to drift and roil slowly as it does in the bays when there is little wave action. The reaeration constant as computed from the graphs ranged from 0.4 to 1.1 g oxygen/m³/hr for 100% deficit, a value less than that of strongly mixed open bays but more than in stratified ponds. Light penetration and bottom heating helped maintain daytime turnover. The General Marine Science class found constant vertical temperature patterns in a diurnal study July 6–7, 1961, measuring temperatures at 1, 5, 10, 20, and 30 cm depth.

Dr. Reid Bryson and Dr. Robert Ragotzkie pointed out verbally that the diurnal measurements of temperature and salinity in the pond could be used as a net radiometer. As a sample, they computed from the temperature curve of the water on a clear day for July 7, 1961, an increase of heat content in the water from dawn to dusk of 300 calories per cm², a heat loss due to evaporation of 128 cal/cm², and a heat loss through conduction of 13 cal/cm² for a total of 441 cal/cm²/day net radiation input. The total insolation received from pyrhelimeter readings was 765 cal/cm².

The hundreds of diurnal temperature curves taken in the bays in the past 5 years as part of diurnal oxygen studies are presumably usable for similar analysis.

pH-CO₂ graphs were made along with oxygen on two days in the summer. Metabolic molar quotients were computed as the ratio of carbon to oxygen in Table 1. These values mainly show some confirmation of the oxygen method and carbon methods. These quotients fall within the ranges found in the prototype environments. Thus in many indices with which bay processes are measured, similar values were maintained by the grass pond system during the summer period.

BLUE-GREEN ALGAL MAT PONDS

In a week after seeding, the blue-green algae developed fresh green new mats over

the bare sand between the transplanted mats so that there was a continuous carpet. A heavy population of corixid water bugs developed. Metabolic curves with an anaerobic nighttime phase with low redox potentials were observed just as in the environmental prototype. A vertical structure of filaments and black organic ooze was maintained like that analyzed by Sorensen and Conover (1962). In November, 1962, with the onset of cold weather, the blue-green algae disappeared and the heavy black ooze below the mats declined. Microscopic examination during the winter showed only diatoms. Then in late March, 1963, the ponds turned bright yellow as the blue-green algae again bloomed as a bottom carpet. Although salinities ranged from oligohaline to hypersaline, the water bugs were abundant in the water over the bottom throughout the summer, winter, and spring.

In Figs. 14–16 are the diurnal properties observed in the blue-green algal mat pond which may be compared with those in the environmental prototype (Odum *et al.*, 1963). The low level of the water allowed the heat and metabolic reception of the sun's energy to be concentrated so that very wide daily ranges of temperature, oxygen, redox potential, and pH were observed (Fig. 14) as in the prototype. Salinity was initially 15‰ but increased to 20–30‰ by evaporation when the metabolic pattern was recorded in Fig. 14. Alkalinity ranged between 2.1 and 2.6 milliequivalents per liter. By July 22 when metabolism was again measured (Fig. 15) the salinity had reached 74.4‰. These wide ranges precluded the development of many kinds of organisms. The persistence of these mats and metabolic patterns in these ponds through the summer confirmed the role of the shallow depth as a mechanism controlling biota. The role of the anaerobic nighttime phase in restricting consumers and thus favoring the deposition of organic matter suitable for oil petrogenesis was proposed earlier (see abstract, Odum and Vick, 1962).

The feasibility of culturing the blue-green mat system in ponds and smaller microcosms has implications for experimental study of sedimentary diagenesis. The diurnal variations in potential and the significance of electrochemical power take off from this ecosystem is explored in a manuscript by Armstrong and Odum (1963).

The comparison of metabolic rates computed for carbon are compared with those for oxygen in Fig. 14. As in the blue-green mat ecosystems in the bay prototypes, a very large molar metabolic quotient (CO_2/O_2) developed. The discrepancy exists even after over-corrections are made for Winkler interference and reaeration. The discrepancies between carbon and oxygen were particularly large after dawn when it may be postulated that oxygen deficits accumulated in the mat during the low oxygen periods of the night were oxidized thus masking the gross photosynthesis. The metabolic patterns of carbon in Figs. 14 and 15 were not greatly asymmetrical and were similar to those in aerobic systems.

The record on August 5–7 in Fig. 16 indicates the rising salinity with evaporation during a two day period as well as the normal metabolic rise and fall of pH. With high pH values and carbonate equilibria shifted mainly toward the carbonate state, photosynthesis in this system is apparently operating directly on carbonate fractions as indicated by the variation in alkalinity.

The steady rise in salinity charted in Fig. 16 reflects the evaporation rate.

DISCUSSION

In these examples, control and morphometry, circulation, and seeding in ponds allowed

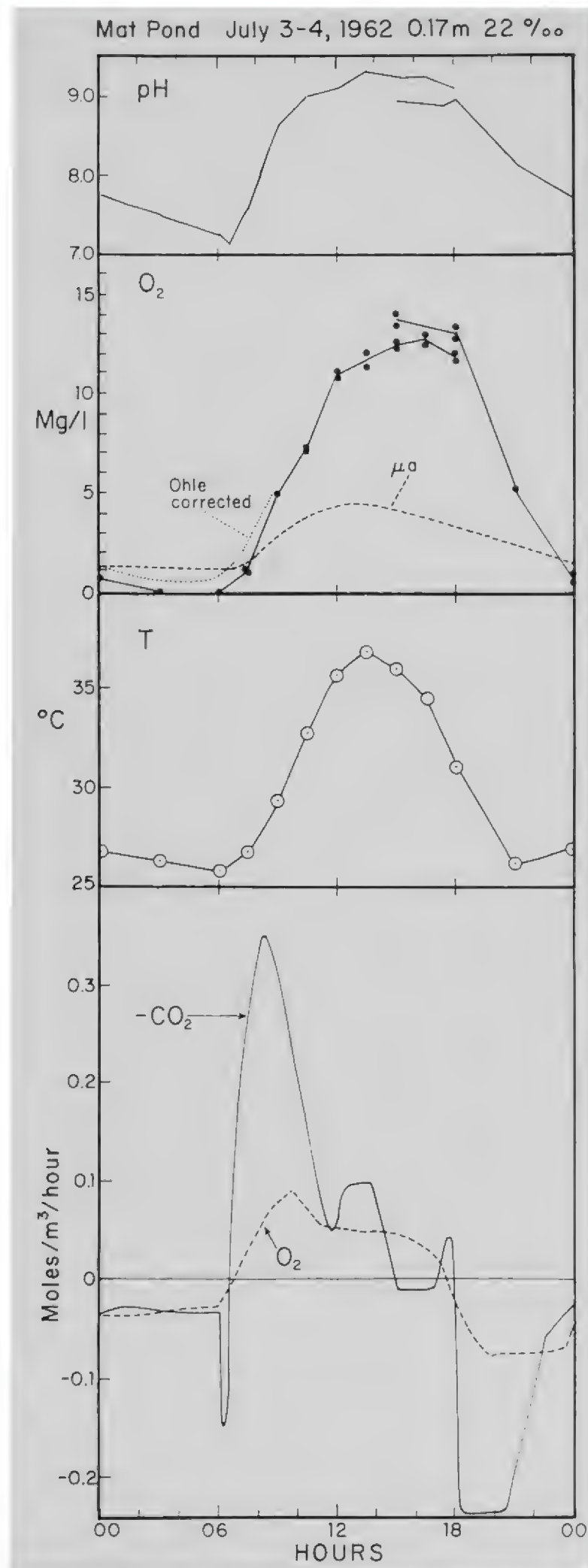


FIG. 14. Diurnal record of pH, oxygen concentration, temperature, and carbon and oxygen metabolic rates, July 3-4, 1962, in the blue-green mat pond. Oxygen rate was overcorrected for reaeration by using K_G 1.5.

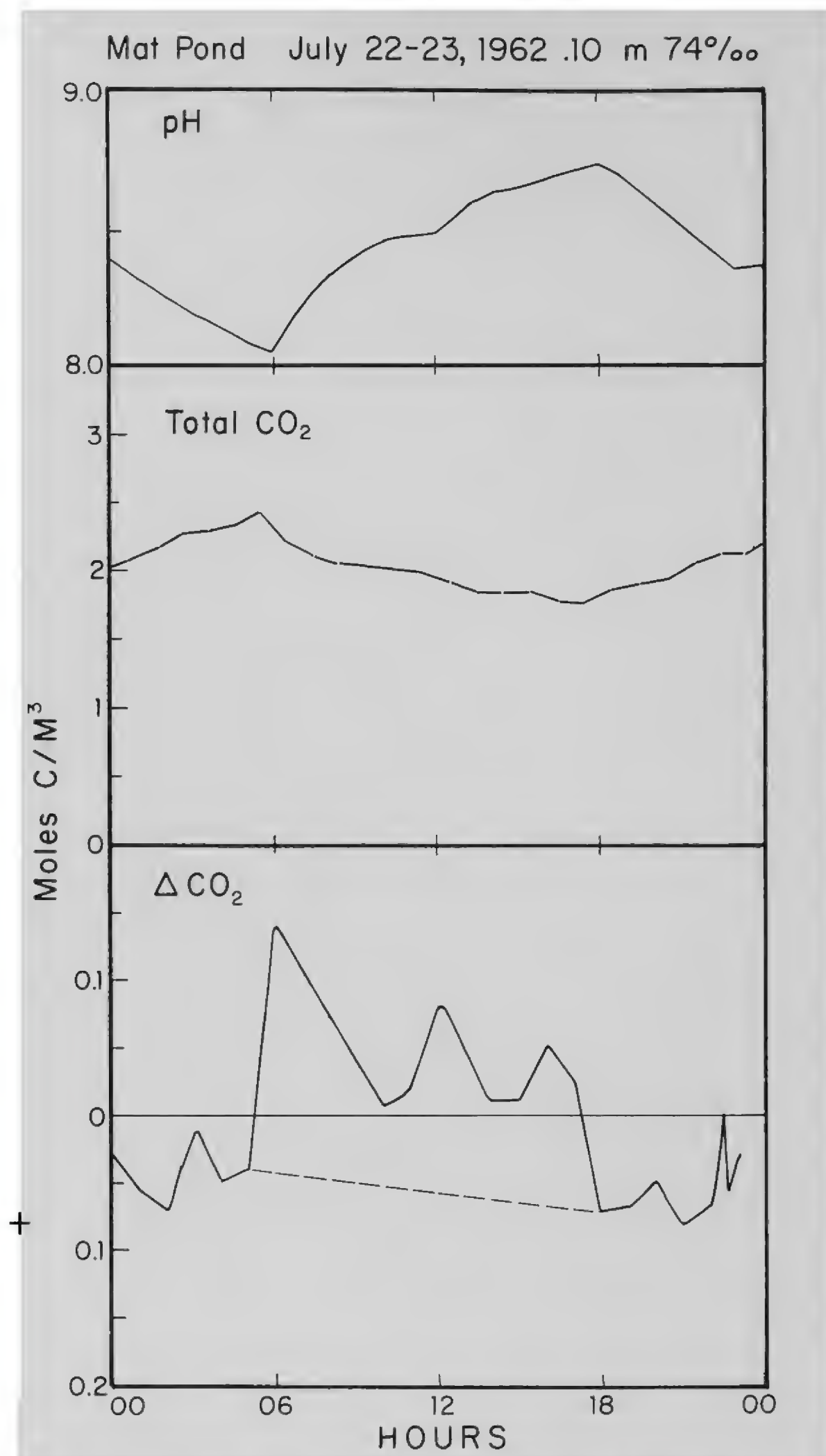


FIG. 15. Diurnal record of pH, total carbon dioxide, and rate of carbon metabolism, July 22-23, in the blue-green mat pond. Alkalinity was 2.1 meq/l.

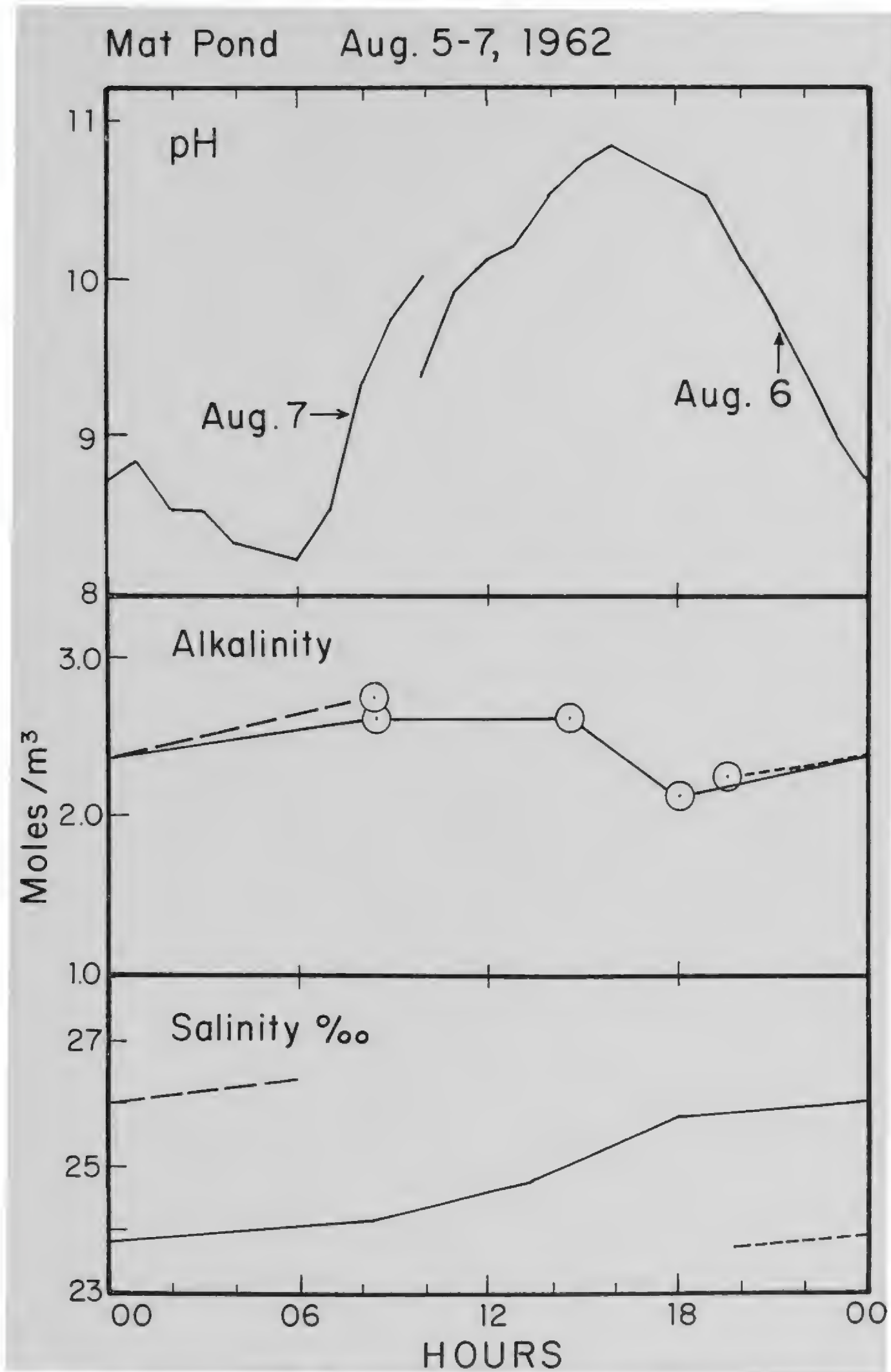


FIG. 16. Diurnal record of pH, alkalinity, and salinity, August 5-7, 1962, in the blue-green mat pond.

productive ecosystems to develop with many properties like those of the bay prototypes being simulated. Not all the properties and components were like the bays, however, as in the instances of rotifers in the reef ponds or the water-bugs in the blue-green mat ponds. The systems cultured were similar but not the same as the prototypes.

Nighttime low oxygen conditions were developed according to the water depth and nutrient concentrations without contributions or organic pollution, especially when respiration exceeded photosynthesis following periods of high productivity. In very shallow waters, low nighttime oxygen tension was apparently a necessary consequence of appreciable productivity.

Discrepancies between carbon and oxygen rates by these methods apparently exist even when potential artifacts such as Winkler interference and inadequate reaeration corrections are eliminated. In the shallow blue-green mat system photosynthetic oxidants apparently go for oxidation of system substances without appearing as dissolved oxygen so that the diurnal oxygen underestimates the metabolism as measured by carbon. A similar process may have been involved in the sequence in the triplicate ponds in which respiration seemed to be exceeding photosynthesis through much of the summer. Diversion of some plus charge "holes" in photosynthetic receptors into some processes other than release of oxygen causes the P/R ratio to be too low and the assimilatory quotient to be too high. Whereas P/R and AQ are objective parameters of the ecosystem, regardless of the diversions of electrons or holes to other processes, the P/R and AQ under these conditions are representing only part of the basic oxidation and reduction processes driven by light. The circumstances resemble those in the Black Sea as studied by Kriss (1963).

Considering all the pond experiments, metabolic rates were mostly less than 6 g oxygen per m² per day without outside pumping energy and somewhat higher in the triplicate reef ponds with auxiliary power supplement through the pump. These values involve photosynthetic efficiencies 0.5 to 3% of visible energy received and were generally somewhat less than the best developed prototype bays.

Considering the cost of marine field work, the pond method for experimental and replicated study of the bay prototypes is attractive for intensive controlled study of metabolism and marine biogeochemistry. For example, radiotracer experiments in ecosystems of known metabolism and populations can be safely followed in the pond systems and used to interpret bay phenomena with some justification.

The pond systems were less diversified than the bay prototypes as expected due to their isolation from large population reservoirs. Total metabolism was also less than in some prototypes. Formulae for ecological engineering such as those tested in this study may be useful in channeling energies into particular food chains in ecosystem culture.

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iron analyses and Mr. Ron Wilson organic matter determinations. Illustrations were done by Mrs. Pauline West.

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Diurnal Metabolism, Total Phosphorus, Ohle Anomaly, and Zooplankton Diversity of Abnormal Marine Ecosystems of Texas¹

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Port Aransas*

Abstract

Diurnal patterns of metabolism, total phosphorus concentrations, Ohle oxidation-reduction anomalies, and species diversities of zooplankton were studied in some abnormal marine ecosystems of Texas under influence of waste effluents. Diurnal measurements of oxygen and pH were made simultaneously at several stations in each bay system. Metabolic computations were made by summing the similar curves from the several stations in a bay, by summing diurnal data from several strata in deeper waters, and by using Ohle corrections and oxygen electrodes to confirm oxygen patterns. Metabolic quotients (CO_2/O_2) were computed where both carbon dioxide and oxygen metabolic rates were obtained. Metabolic quotients ranged from 0.4 to 1.9. Some photosynthetic efficiencies were computed with pyrhelimeter data.

A bleedwater lagoon with a benthic blue-green algal mat ecosystem contained 26 to 876 ppb total phosphorus, little or no zooplankton, large and variable Ohle anomalies (0.3 to 2.8 ppm both oxidizing and reducing), a diurnal curve with nearly zero oxygen at night but super-saturation in daytime, a post sunrise oxygen deficit, a moderate efficiency 1% to 3% of visible light energy received, and an excess of respiration over photosynthesis. In natural briny conditions of the Mexican Laguna Madre at 121‰, oxygen remained nearly zero through the day with little evidence of photosynthetic metabolism.

A seafood waste system in Conn Brown Harbor at Aransas Pass, Texas maintained total phosphorus 53–306 ppb, zooplankton species diversities 4–14 species per thousand individuals, large amplitudes of diurnal oxygen and pH curves, respiration in excess of photosynthesis, and photosynthetic efficiencies of 0.8% to 3.8% of visible light energy received. The Brownsville Shrimp-boat channel with less concentration of wastes had 10 to 200 ppb total phosphorus and 8 to 18 species of zooplankton per thousand individuals.

Ship channels at Houston and Corpus Christi receiving heavy influxes of wastes varied markedly depending on conditions of flushing with phosphorus ranging from 2 ppb to 1290 ppb, species diversities ranging from 1 to 11 species per thousand or no zooplankton, some diurnal metabolic curves of large amplitude but also some of little amplitude, some wide-ranging patchy conditions, large Ohle anomalies up to 7 ppm both oxidizing and reducing, large and variable pH fluctuations, and oxygen stratification with near anaerobic bottom conditions.

Shallow bays receiving wastes from the ship channels and peripheral sources, Nueces Bay, Corpus Christi Bay, and Galveston Bay contained total phosphorus contents 2 to 2000 ppb, zooplankton species diversities 2 to 19 species per thousand, Ohle anomalies up to 1.4 ppm, and metabolic curves ranging from almost no metabolism to 60 g/m² per day usually with respiration in excess of photosynthesis, and patchy conditions in distribution of oxygen and pH with large ranges.

Abnormal bays were usually but not exclusively higher in phosphorus, lower in diversity, more erratic in diurnal patterns, with larger Ohle anomalies, and had recognizably extreme diurnal meta-

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bolic patterns. A classification of diurnal patterns associated with waters receiving wastes included: (1) excess of photosynthesis over respiration (1 case); (2) excessive respiration with undersaturation continuously but with a photosynthetic pattern; (3) regular but amplified diurnal pattern; (4) toxic system with near saturated non-metabolic pattern; (5) wide ranging patchy condition in oxygen and pH properties; (6) stratified channel with reduced bottom waters; (7) diurnal deficit regime with nocturnal anaerobic curve and large daytime photosynthesis.

Many of the Texas Bays in the 1960-1962 period were demonstrably affected by the wastes. The phosphorus data, Ohle anomaly measurements, the counts of zooplankton species diversity, photosynthetic efficiencies, and diurnal curve characteristics were found to be sensitive means for indicating normal or abnormal conditions.

Introduction

Behind the beach line of Texas into a million and a half acres of shallow green bays, the expanding urban culture of coastal Texas is accelerating its rates of marine waste discharge. With little daily tide and relatively little exchange of water with the open Gulf, the contributions of the rivers, the Gulf tides, and the waste flows are stirred by the strong Texas winds to provide new regimes with corresponding changes in the ecological systems which result. What kinds of abnormal ecosystems are developing? How are these systems identified and contrasted with the previous ecological systems? How is the total metabolism and productivity affected? What sensitive indicator techniques are available for monitoring the areal extent of the system types?

Considerable knowledge exists on the marine pollution of Texas bays mainly in a number of unpublished reports of the Texas Game and Fish Commission, the Texas Health Department, Philadelphia Academy of Sciences, Texas A. and M. Research Foundation, and many of the coastal industries. Fish kills in Offatts Bayou, a corner of Galveston Bay near Galveston, were described by Gunter (1942), and the dinoflagellate blooms and patchy oxygen patterns there were described by Connell and Cross (1950). Bacterial patterns related to wastes were traced by Oppenheimer, Travis and Woodfin (1961) for several bays. Detailed studies of biological and physical properties related to wastes were given by Chambers and Sparks (1959) and Hohn (1959) for the Houston Ship Channel.

In a sequence of previous papers, the normal patterns of total photosynthesis, total respiration, and total phosphorus were presented for some Texas Bays relatively less affected by the urban waste flows (Odum and Hoskin, 1958; Park, Hood, and Odum, 1958; Bruce and Hood, 1959; and Odum and Wilson, 1962). These papers report the use of diurnal curve methods where the conditions of thorough mixing and shallow depth without much tidal transport or stratification are particularly favorable. It was also noted that such methods provided sensitive means for assay of abnormal regimes and their metabolism (Odum, 1960b; Copeland and Dorris, 1962).

In this paper, these measurements are made in ecosystems of the Texas marine bays where waste flows are important. Effort was concentrated on 3 types of abnormal ecosystems and on some zones between the abnormal systems and normal systems where indices of ecosystem function were useful for delimiting the boundaries of influence between normal and abnormal types.

The three main types of systems studied were as follows:

I. *Bleedwater-bluegreen system*. A complex of diurnally oscillating aerobic and anaerobic conditions develops in very shallow marine bay waters receiving the bleedwater wastes of oil drilling. The very hard waters, rich in nutrients and contaminated with

some oil, combine to produce massive bluegreen algal mats and associated sulfur bacterial phenomena such as red water. An example of this complex was studied in a lagoon three miles south of the Flour Bluff toll station on the west side of the Upper Laguna Madre of Texas (see Fig. 1). The natural brines of the Mexican Laguna Madre were studied for comparison.

II. *Seafood waste system.* A complex of highly metabolic plankton waters develops where regular discharges of wastes from packing of shrimp and crabs are returned to the sea waters. Such a complex was studied in Conn Brown Harbor and Brownsville Ship Channel (see Figs. 2, 3 and 4).

III. *Composite ship channel waste system of an oil city.* The multiple pollutions from refinery wastes, municipal wastes, and wastes from chemical processes related to the oil industry exist in the Houston Ship Channel which discharges into upper Galveston Bay (Figs. 5 and 6) and in the Corpus Christi Ship Channel which connects with Corpus Christi Bay (Fig. 7). These two composite waste systems, representing extreme concentrations of waste in a marine environment, were studied and their influence on adjacent bays followed with the several methods. The Houston Ship Channel was diluted and flushed at irregular rates by the San Jacinto River into Galveston Bay as shown by Chambers and Sparks (1959) whereas the Corpus Christi Channel was discharged by exchange at its connection to Corpus Christi Bay without river flow and by steady pumping of channel water through the Central Power and Light Company cooling systems out into Nueces Bay, water being replaced from Corpus Christi Bay through the mouth of the channel. A complete map of the Houston Ship Channel and adjacent industrial plants is given in Chambers and Sparks (1959).

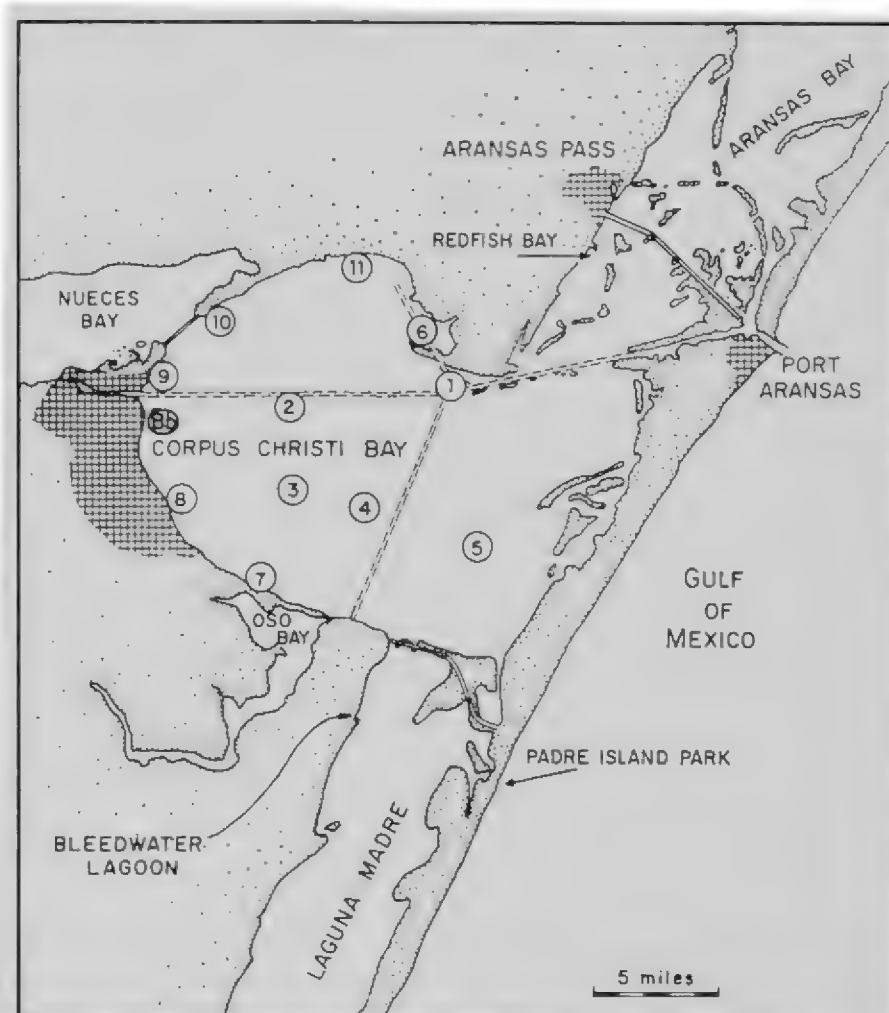


FIG. 1. Corpus Christi Bay with adjoining smaller bays. Numbers indicate stations. Dashed lines indicate ship channels.



FIG. 2. View of Conn Brown Harbor, Aransas Pass, Texas, location of sea-food waste discharge, Feb. 1, 1960; view from the east.

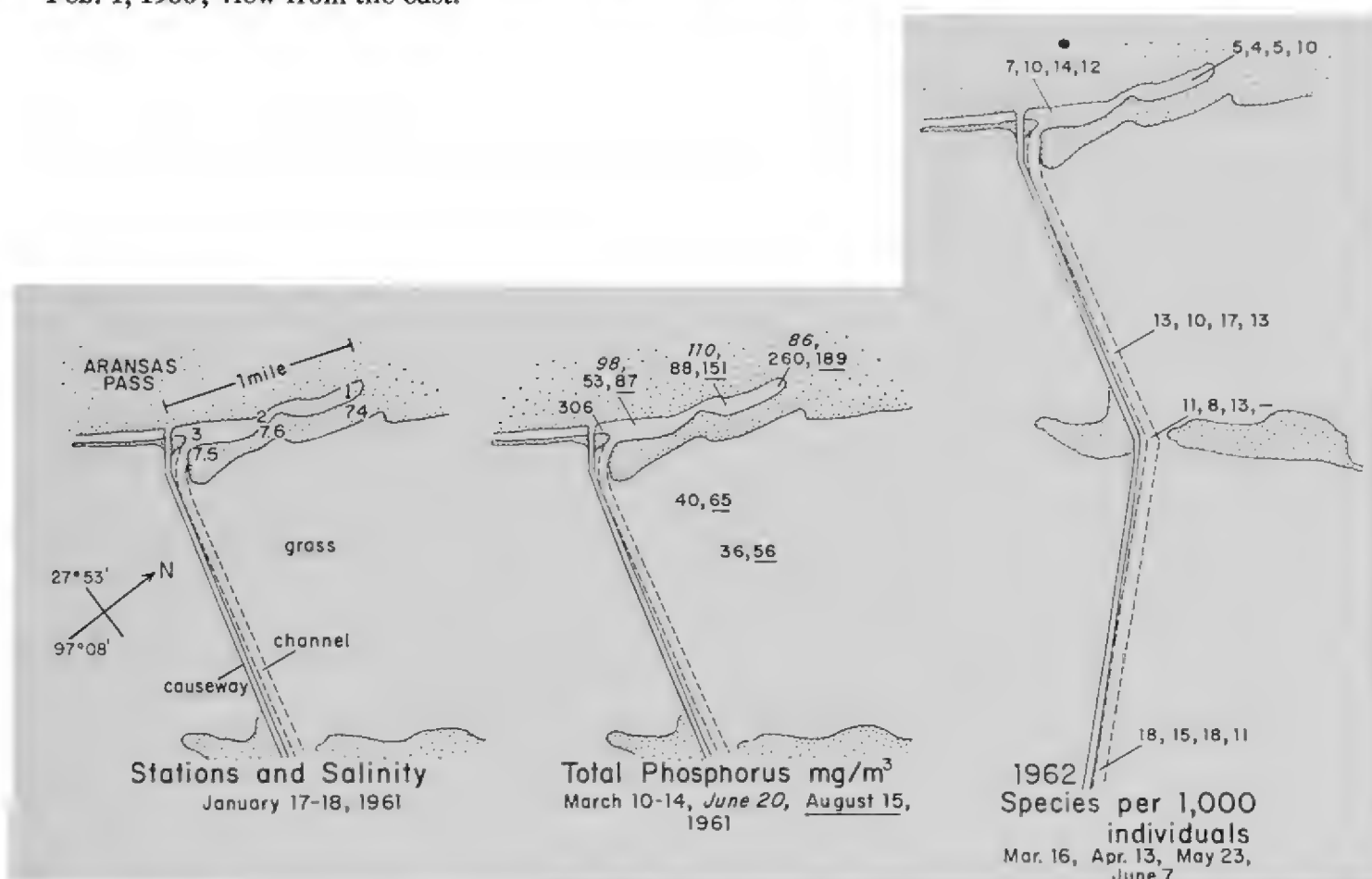


FIG. 3. Distribution of variables at stations in and near Conn Brown Harbor, Aransas Pass, Texas. Diagram on the right depicts channel through Aransas Pass jetties.

Methods

The methods were extensions of those used in the studies of the normal bays cited with the addition of some new features.

DIURNAL OXYGEN METABOLISM MEASUREMENTS

The diurnal curve procedures set out in Odum and Hoskin (1958) were used with several changes. Generally, it was possible to run several concurrent stations making it

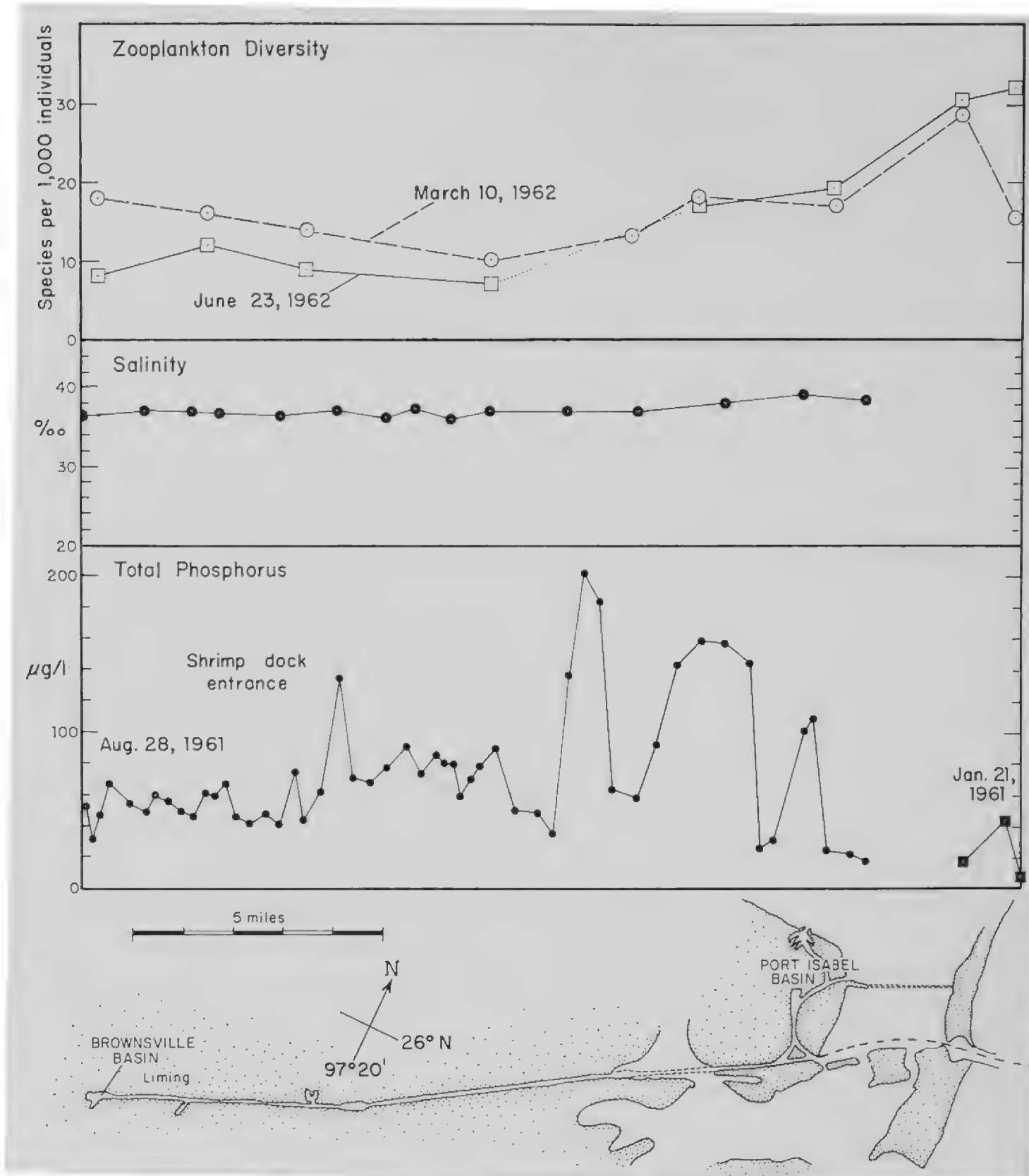


FIG. 4. Distribution of variables in the Brownsville Ship Channel. Graphs and map drawn to horizontal scale.

possible to provide more confidence about the representativeness of the curves used for computations. Instead of determining the diffusion constant from the diurnal curve on the basis of an assumption about respiration the process was reversed. The estimates of diffusion constant ($k = 1 \text{ gm/m}^3 \text{ per } 100\% \text{ deficit}$) based on previous diurnal curve work in normal bays (Odum and Wilson, 1962) were used for diffusion corrections and the night-time respiration obtained by subtraction. Where interference was suspected with Winkler processes at low oxygen tension, some oxygen electrodes were also used. The Jarrel-Ash-Kanwisher portable battery apparatus was used to survey microenvironments in the bleedwater system. Recordings were made from a Mancy-Okun (Mancy and Westgarth, 1962) electrode operating in the field from portable generators. Most of

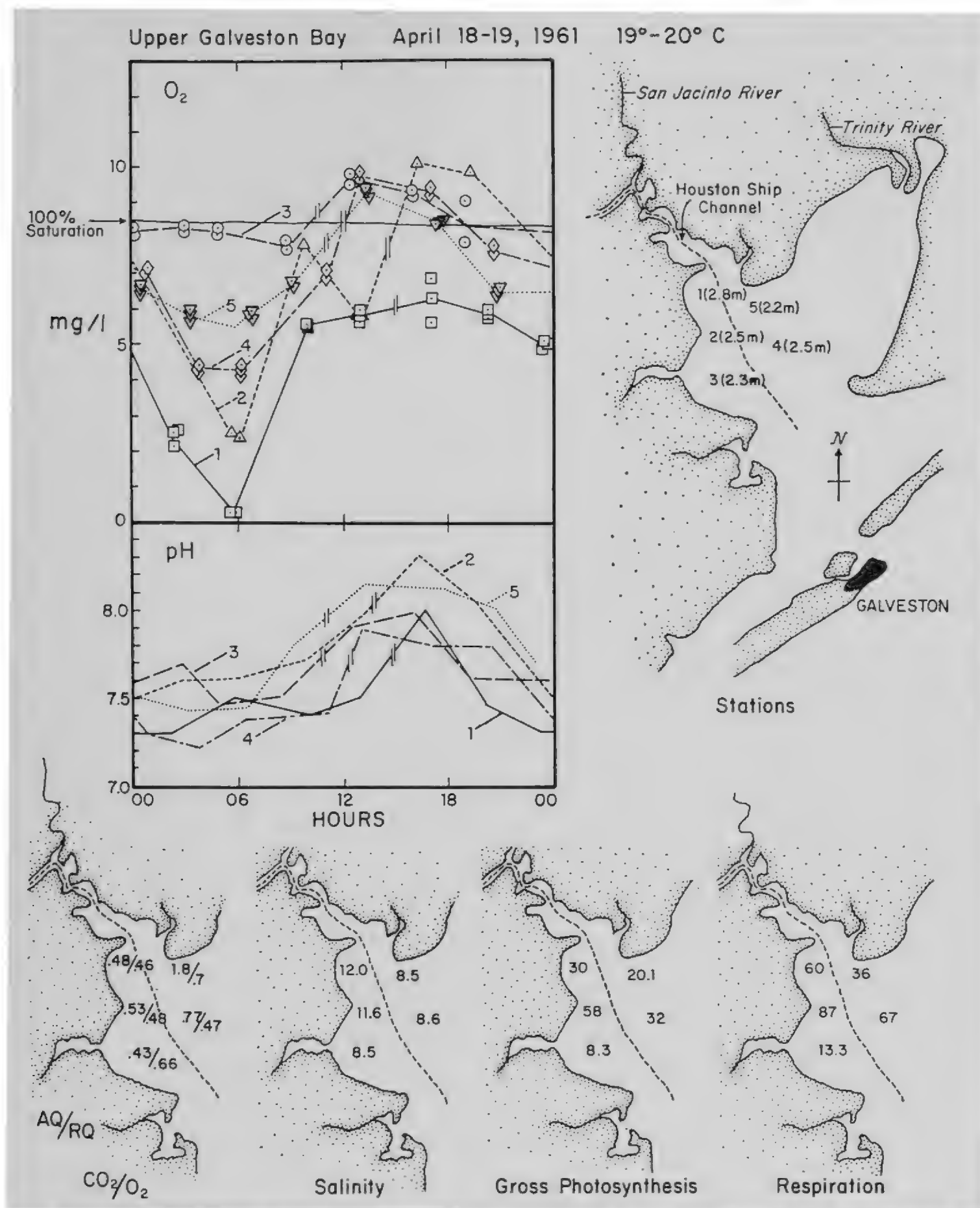


FIG. 5. Distribution of variables in Upper Galveston Bay, April 18-19, 1961 including diurnal record of oxygen, pH, and derived quantities.

the graphs were prepared from data taken by standard Winkler analysis corrected for interference with the Ohle anomaly procedure (Ohle, 1953).

OHLE ANOMALY

The Ohle procedure (Ohle, 1953) was used not only for a Winkler correction but also as a measure of oxidizing and reducing substances present that may be related to

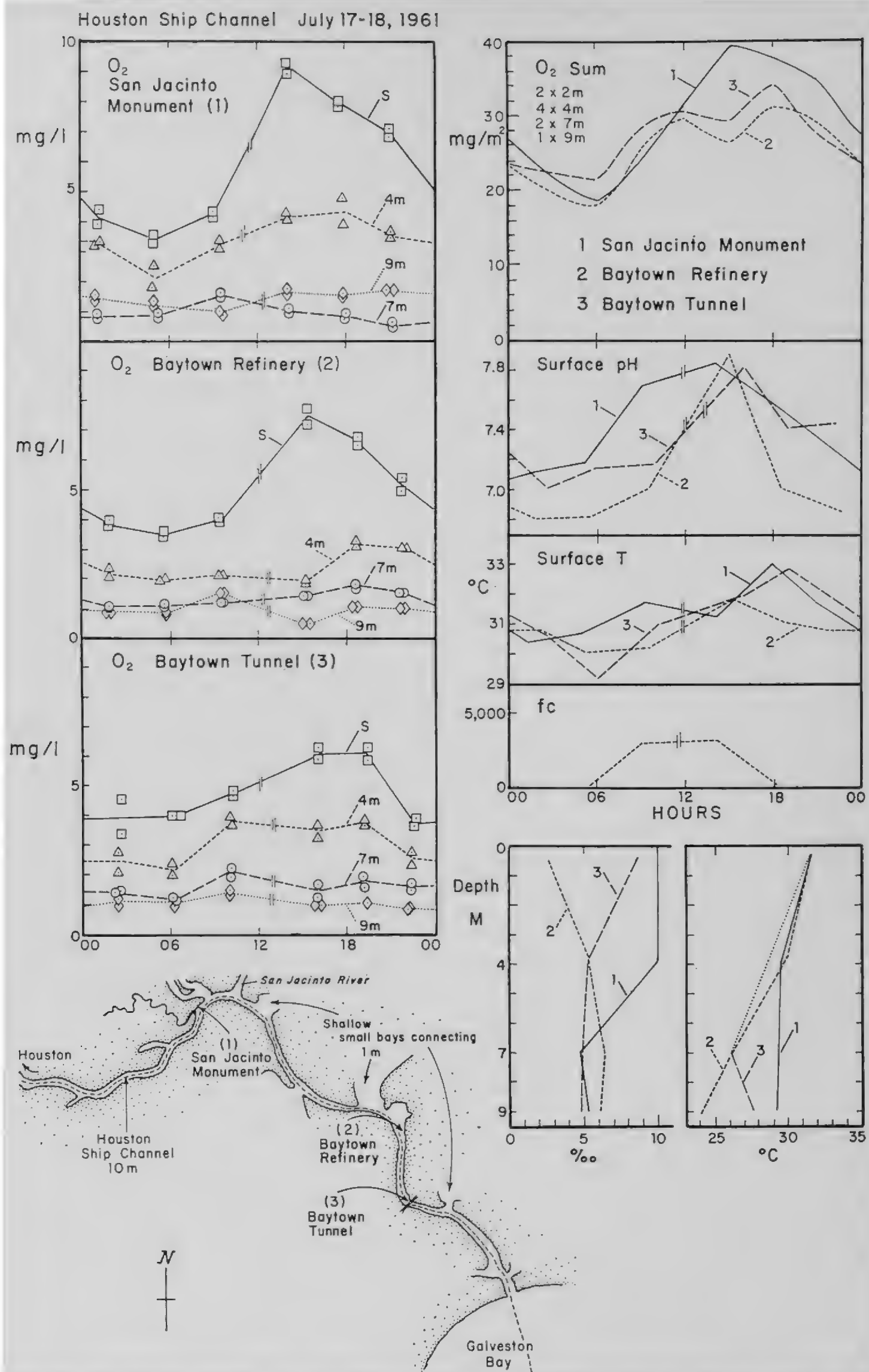


FIG. 6. Diurnal oxygen, pH, and temperature patterns at 3 stations in the Houston Ship Channel July 17-18, 1961. Four levels are given at each station and a rough calculation of the total oxygen in vertical column is made for the diurnal period.

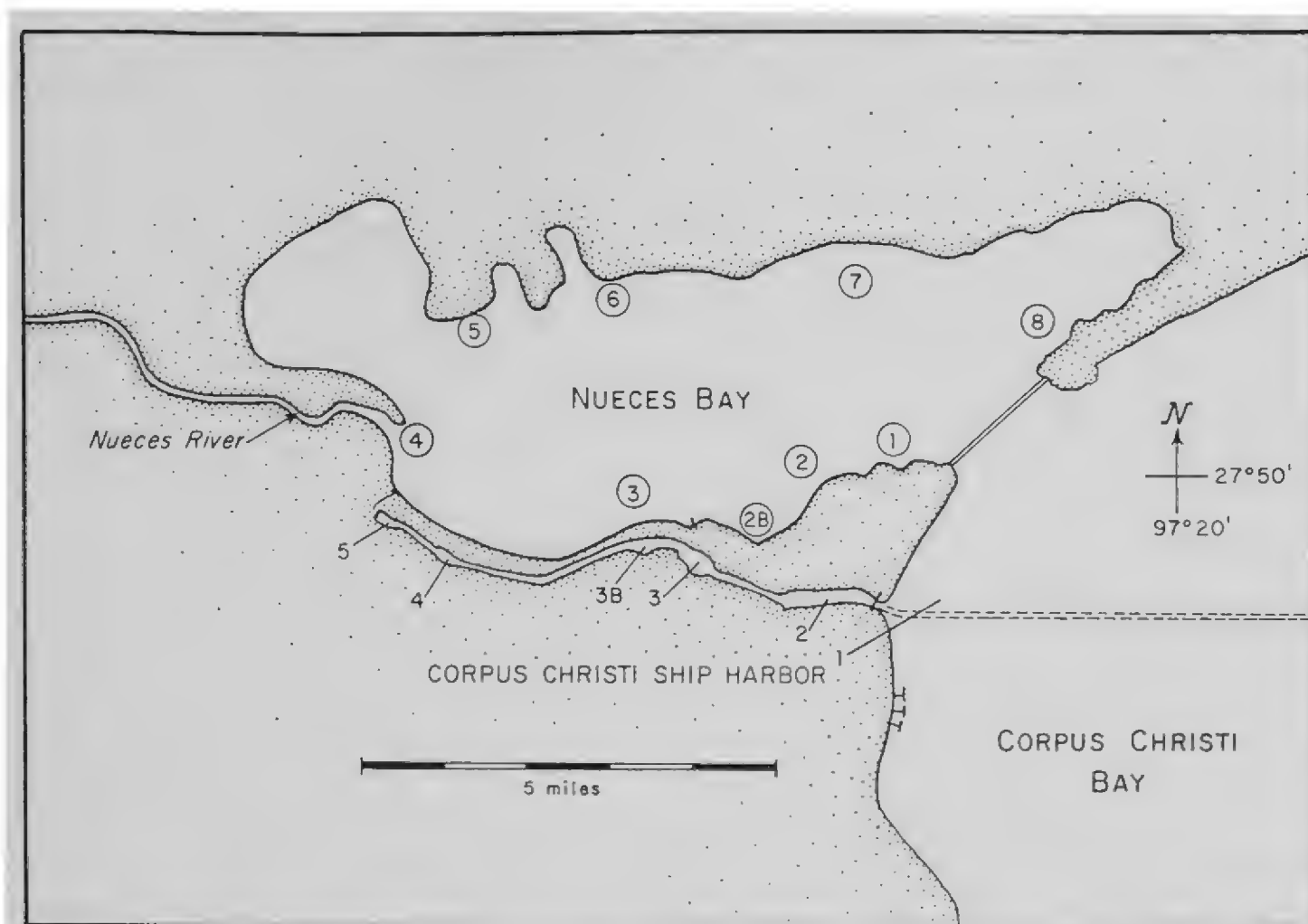


FIG. 7. Stations in Nueces Bay and in Corpus Christi Ship Harbor.

waste distribution. The procedure is outlined in Table 1. A precise amount of the Ohle iodine-iodide reagent (1.0 ml) was added to duplicates so that any oxidizing or reducing that might take place abnormally in the Winkler process would presumably work on the added iodine or iodide. By leaving the manganous sulfate out of one set of duplicates, the contribution of dissolved oxygen to the final thiosulfate titration was eliminated. Subtracting the Ohle control from the Ohle plus oxygen titrations, provided an Ohle-Winkler analysis from which interference either of oxidizing or reducing nature had been removed.

The Ohle anomaly was then calculated by subtracting this Ohle Winkler analysis from the regular Winkler analysis to obtain the amount of interference in mg/liter. Where the standard Winkler analysis was larger than the Ohle Winkler, the anomaly indicated oxidizing interference (plus); where the standard Winkler analysis was smaller than the Ohle Winkler, reducing interference (minus) was indicated. These anomalies were plotted on graphs and maps.

TABLE 1

Ohle anomaly procedure

Collect a half carbuoy of water; homogenize by swirling 3 minutes; siphon 6 duplicates into Winkler bottles. Add reagents as follows:

Bottles 1 & 2:	Follow regular Winkler procedure.	} Subtract to get the Ohle Winkler	} Subtract to get Ohle anomaly
Bottles 3 & 4:	Add Ohle iodine-iodide reagent; follow with regular Winkler procedure.		
Bottles 5 & 6:	Add Ohle iodine-iodide reagent; follow with regular Winkler procedure except omit manganous sulfate.		

Some oxygen graphs were corrected for interference by adding the Ohle anomaly. However, demonstrating that there are substances which are interfering with the Winkler process to the extent of the anomaly did not guarantee that oxygen was present. A zero oxygen analysis and evidence of reducing interference in the Ohle test may or may not indicate there is oxygen present. One cannot, therefore, make a blanket correction to oxygen curves in their anaerobic periods.

DIURNAL pH-CO₂ METHODS

The diurnal pH methods were improved versions of those reported in Beyers and Odum (1959) involving empirical pH versus CO₂ change graphs. Principal improvements are described in papers by Beyers (1963) and Beyers et al. (1963). These include a revolving tonometer for equilibration of CO₂ water, convenient tables, and a computer program for calculations. Field data for pH were taken with a Model W and with zero-matic model Beckman meters operating from generators.

DIURNAL CURVES IN STRATIFIED WATERS

Most of the diurnal curve studies made in Texas marine waters have concerned shallow, continuously-mixing waters. However, some of the harbors and channels reported in this paper were either stratified, or had vertical mixing rates of the same order as the metabolic rates. Therefore, vertical gradients with exchanges from one stratum to another developed. McFarland and Prescott (1959) in their kelp study computed diurnal changes in each of several arbitrary vertical layers. They used an inter-layer diffusion constant derived in the same way that the reaeration constant is calculated from the rates of diurnal metabolism and saturation gradient. This method may require more data and more accuracy than is ordinarily available, but it does provide an independent way of obtaining the Austausch vertical turbulence coefficients. For these studies, however, the diurnal curve method was applied by first adding the oxygen concentrations of each layer to obtain a graph of the total oxygen per area. In some instances this involved adding the data from several stations. The rate of change was computed from this area-content graph. The reaeration constant was applied according to the surface saturation graph. Although continuous, vertical mixing was sometimes evident from the similarity of vertical temperature values, the area-sum procedure was generally used for the harbors and channels. With this method, the diffusion of oxygen from one layer to the other does not affect the sum for the vertical column.

One of the observations made in the bays receiving wastes was the patchy character as observed in variation between duplicate samples and especially duplicate stations. The heterogeneity of the diurnal curves in the Nueces and Galveston Bays prevent any one curve from providing statistical evidence as to representativeness for metabolic calculations. Metabolic changes accumulated at one station drift to another, and show up as lags in the peaks of diurnal curves. If water moves from shallow to deep areas, over highly metabolic bottoms, through fish schools, or receives wastes, a very heterogeneous character may result. Just as the vertical layers were summed thus including oxygen that was transferred from one layer to another, so in large bays with drifting patches of water of different metabolic quality, it was possible to average to obtain a single oxygen graph for the bay.

Although the pH-CO₂ method has some advantages for the study of large bays such as reliable recorder output, minimal reaeration effects, speed and minimal interference, the oxygen methods were more trustworthy because of the rough conditions of operation in small boats with spray, varying power in generators, and human errors where field assistants have limited experience with electronic equipment.

Bottle experiments were made for comparison with the free water methods. Dark and light bottles were suspended at 0.5; 2.0; and 3.0 meters for six-hour periods. One series of radiocarbon measurements was made in bottles suspended for six-hour periods following the procedures summarized by Strickland (1960). Bottles were filled from various levels with a submersible pump.

ZOOPLANKTON DIVERSITY

The much used principle that abnormal new ecosystems affected by man's culture have less diversity of species was investigated for these marine bays using zooplankton counts and Gleason's (1922) species diversity index. Margalef's (1957, 1961) several measures of information content of species distributions were computed using a computer program written by Neal Armstrong of the Institute of Marine Science. It was found theoretically more suitable to compute the information content of the number of species only, a measure not computed by Margalef. Following Brillouin (1957) informational content of the number of circuits is the log of the number of circuits. Using each species as a biogeochemical food circuit (Odum, 1960a), the informational content as a measure of organization of the ecosystem's species is the log of the number of species. It may be reasoned, consistent with the vast literature on species isolation mechanisms, that an ecosystem does provide means for insulation of its separate species circuits. Consequently, this species-information represents organization that has been specified, whereas much of the informational content that Margalef computed represents the uncertainty that has not been specified by organizing influences of the ecosystem.

Thus, the informational content of the species as a measure of system organization may be expected to decrease as abnormal, newly-organizing, less-evolved system combinations resulting from wastes replace the older evolved systems. In this paper, the diversity index was compared to other symptoms of abnormal regimes such as unusual phosphorus and metabolic patterns. The reader who wishes may convert to bits by taking the logarithm.

In the early phase of the investigation zooplankton collection was done with a Clark-Bumpus sampler fitted with a #2 net towed for 6 minutes. Insufficient numbers of plankton were obtained, however, partly because of the seasonal paucity of the plankton during the winter, and the relatively small (approximately 6 m³) volume of water filtered during each haul. To alleviate these difficulties a 1/2 m net with #12 mesh netting was used for the balance of the investigation. A #6 mesh net was used as a stand-by; in some instances the clogging resulting from the catch of numerous coelenterates was excessive with a fine mesh net.

The hauls were all made at the surface for 4 minutes at approximately 2 knots. To minimize the clogging, the duration of the hauls with the 1/2 m net was reduced to 4 minutes, instead of 6 minutes, as the population densities increased in March.

One thousand individual zooplankters were counted and the number of cumulative species were recorded for 10, 100, and 1000 individuals, thus abbreviating the semi-

log plot of species and individuals (Odum, Cantlon, and Kornicker, 1960).

Data were plotted as "species per thousand individuals", a number that may be compared for plankton, trees, microbes, etc.

In all the bays and in the Gulf waters near the shore, the copepod *Acartia tonsa* was dominant throughout the year with 1 to 3500 individuals per m³.

In a technique test, counts made at 4 hour intervals Dec. 28–29, 1961, at Port Aransas were 11, 8, 12, 10, 12 species per 1000. At the same time the number of plankters per cubic meter varied from 75 or less during daylight to 375 or more during darkness.

TOTAL PHOSPHORUS

Total phosphorus has long been used as a sensitive indicator of abnormal imbalances of respiration over photosynthesis or of abnormal wastes of many kinds. Its usefulness as a waste tracer in shallow marine bays in Florida was shown previously (Odum, 1953a).

Total phosphorus procedures were designed to show larger differences in general nutrient level in the water, in the plankton, suspended clays, organic substances, etc., over the range from 2 to 2000 parts per billion.

Water was collected and stored in glass stoppered 125 ml pyrex bottles previously cleaned with sulfuric acid and rinsed with distilled water. Water was emptied into 250 cc erlenmeyer flasks; the bottle walls were scrubbed with a rubber policeman and washed with perchloric acid which was then added to the flasks. Samples were digested by evaporation down to fuming condition with care that samples were removed before loss of white vapors. Then the salty paste residues were diluted with 100 cc of distilled water. The colorimetric analysis was made with the ammonium molybdate-stannous chloride procedures and compared with standards. A blanket 20% salt correction may be used, although data are reported without it here.

The large magnitude and range of total phosphorus in these waters justified elimination of procedures that would be used in the open sea for maximum accuracy such as field freezing of samples, making standards in phosphorus free sea water, high pressure autoclave digestion, and special glasses. New phosphorus data in this paper can be compared with earlier data (Odum and Wilson, 1962).

PYRHELIOMETER AND FOOT CANDLE DATA

Starting in 1961 a 50 junction Eppley pyrhelimeter was mounted on the roof of the Institute of Marine Science. Recordings on a Yellow Springs Instrument amplifier-Rustrak recorder system were calibrated with a low resistance Weston precision microammeter using the Eppley Company calibration relating current to g-cal/cm² per hr. In the field the hand exposure meter was used: GM Golden Crown Meter with approximate foot candle scale provided by the manufacturer with its incident light attachment. Under rough field circumstances the values must be regarded as very approximate. Where field measurements were within 25 miles of the Institute, it was considered feasible to compare pyrhelimeter and foot candle records. With the cumulus types of clouds in summer, large local differences may be expected, but during frontal regimes with stratiform clouds, similarities may be expected.

An RG-8 glass filter box was placed over the pyrhelimeter to exclude the visible light,

the difference being the visible light available for photosynthesis. This value varied with cloud type, but the 50% often quoted in the literature was about right for sunny days. Wind measurements were made in the field with a hand anemometer.

Results

In the following paragraphs are introduced diurnal graphs and aerial maps of properties in the abnormal systems and nearby bays.

I. BLEEDWATER-BLUEGREEN SYSTEM

In Figs. 8 and 9 are presented diurnal data for a station in the bleedwater-bluegreen system on the edge of the Laguna Madre in 1961 at a time when benthic blue-green growths were heavy and the water was pink, and in 1962 when the pink color was less marked. In the very shallow, highly saline waters, there was a large diurnal range of conditions from nearly anaerobic to aerobic states with corresponding pH change due to carbon dioxide metabolism and other possible effects such as may have resulted from the changing oxidation conditions in the sulfur states. Whereas the carbon dioxide rate of change curve as inferred from pH indicated photosynthesis throughout the day, the oxygen curve for the first 3 hours after sunrise remained close to zero on the membrane

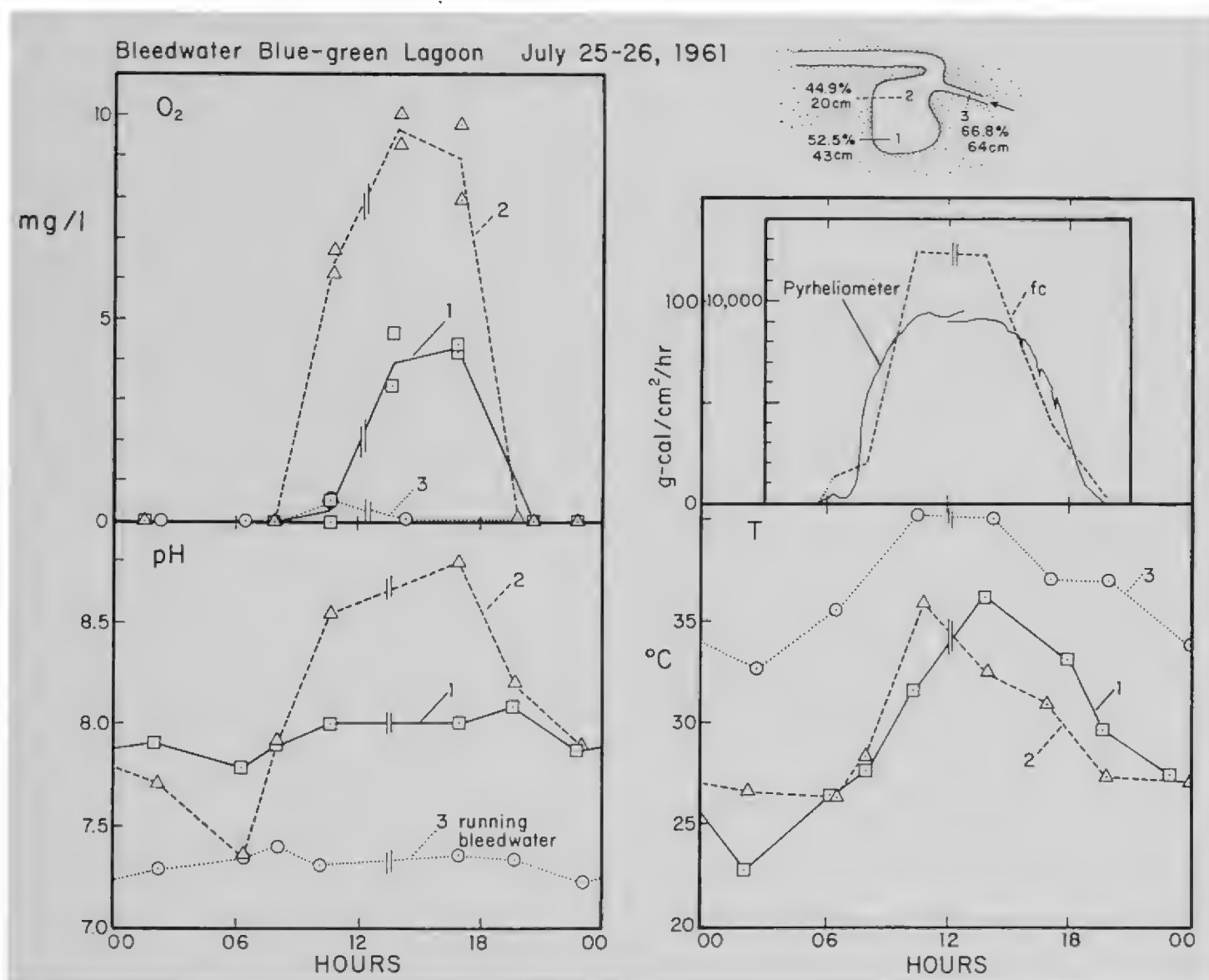


FIG. 8. Diurnal record of oxygen, pH, temperature, and light in the bleedwater lagoon containing bluegreen algal mats July 25-26, 1961. The position of stations is indicated in the sketch map. Bleedwater is entering at station 3; the lagoon discharges into the Laguna Madre to the left.

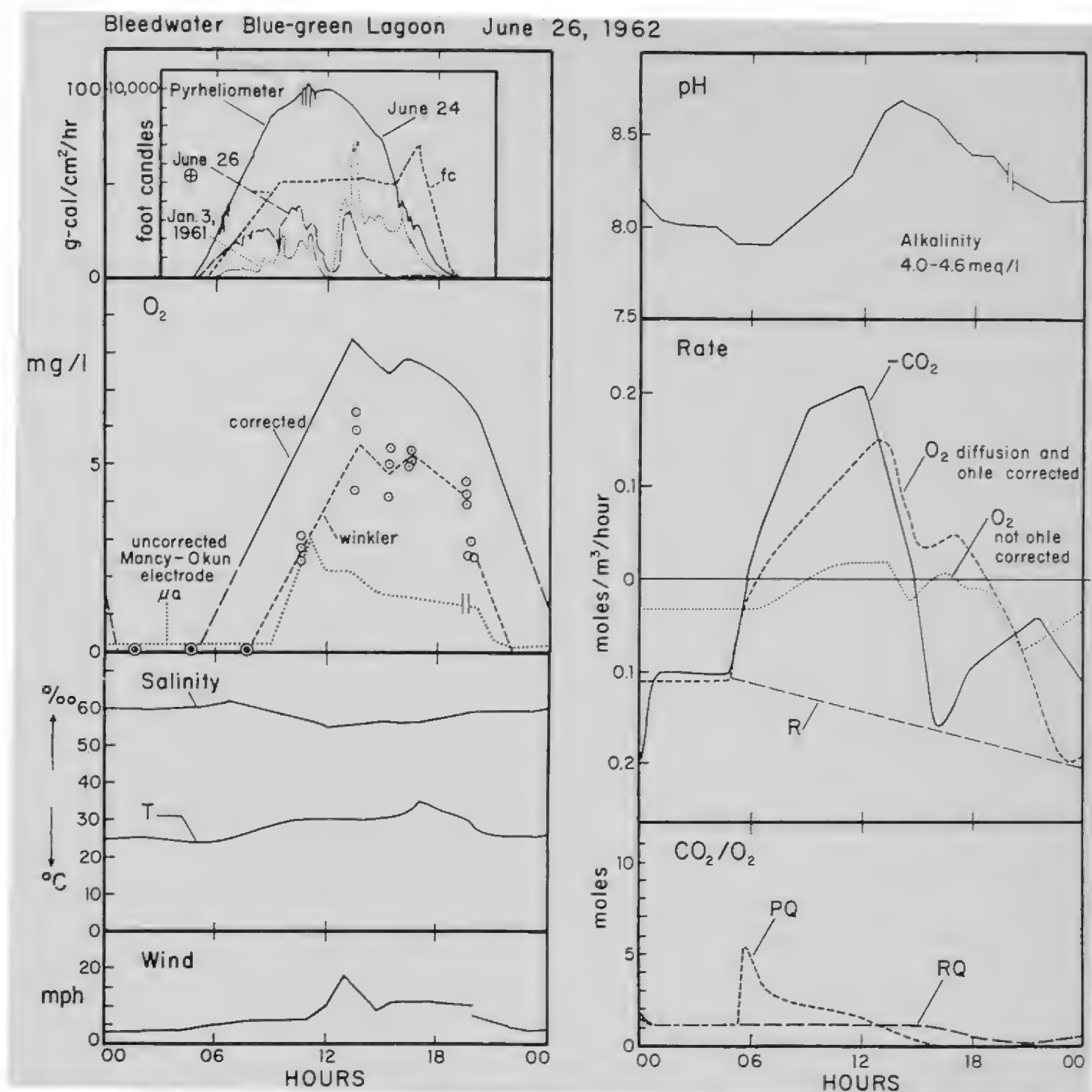


FIG. 9. Diurnal record of variables in the bleedwater lagoon June 26, 1962. Rates of change of oxygen are plotted with and without Ohle correction. Rates of change of carbon dioxide are plotted with negative values up as computed from the pH data. Metabolic quotients are plotted for the Ohle-corrected graphs. A winter radiation graph is included for comparison with sunny and cloudy summer days.

electrode suggesting that an anaerobic deficit of reduced compounds were being oxidized by oxygen as fast as the oxygen was formed.

Ohle anomalies were done a week later on July 3 (Table 2) at which time stations had up to 2.71 ppm of apparent oxygen decrease due to reducing substances. In contrast some stations further out in the bay had reversed anomalies indicating oxidizing effects. Also, quite variable results were found on July 16, 1962 (Table 2). Apparently the substances in the water at different places and times of day may have quite different effects on the Winkler process. A Kanwisher (Jarrel-Ash Co.) oxygen analyzer was carried over the lagoon by wading observers on a sunny day and the oxygen tensions explored in microenvironments. Near zero oxygen tensions were observed in the deeper waters, visibly turbid with pink bacterial activity, but as the probe was moved into the shallower water the oxygen rose immediately into the supersaturation range associated with the brilliant colored blue-green algal bottom mats. Mancy-Okun electrode recordings

TABLE 2
Ohle anomaly data

		1	2	3	4	5
		Winkler	Ohle plus Winkler	Ohle only	Corrected Winkler 2-3	Anomaly 1-4
Bleedwater-bluegreen system						
July 3, 1962	Station 1	4.46	10.99	5.15		
		5.15	10.05	1.29		
			4.80	10.52	3.11 7.41	-2.71
	Station 2	0	1.56	0.50		
		0	1.64	0.20		
			0	1.60	0.35 1.25	-1.25
	Station 3	5.61	9.91	3.54		
		6.52	(4.61?)	3.44		
			6.07	9.91	3.49 6.42	-0.35
	Station 4	6.02	10.13	4.15		
		6.04	10.59	3.47		
			6.03	10.36	3.81 6.55	-0.52
	Station 5	5.26	7.52	3.57		
		5.30	7.13	3.59		
			5.28	7.32	3.58 3.74	1.54
July 16, 1962, Dawn	Station 1	0	0	0	0 .....	.....
	Station 2	0	0	0	0 .....	.....
	Station 3	4.46	7.35	4.34		
		4.54	7.54	3.98		
			4.50	7.43	4.16 3.27	1.23
	Station 4	4.21	7.62	3.81		
		3.47	7.68	3.76		
			3.84	7.65	3.79 3.86	-0.02
	Station 5	3.92	7.18	4.50		
		3.30	7.48	6.89		
			3.61	7.33	5.69 1.64	1.97
July 16, 1962, Sunset	Station 1	0.99	4.85	2.10		
		1.03	4.26	0.87		
			1.02	4.55	1.48 3.07	-2.05
	Station 2	0	0	0	0 .....	.....
	Station 3	5.77	7.87	3.33		
		4.49	8.13	3.51		
			5.13	8.00	3.42 4.58	0.55
	Station 4	5.35	8.90	3.06		
		5.30	8.89	2.96		
			5.32	8.90	3.01 5.88	-0.56
	Station 5	5.54	12.35	3.43		
		5.73	9.30	3.43		
			5.64	10.82	3.43 7.39	-1.75
Houston Ship Channel						
August 22, 1962						
Baytown Refinery						
1000	Surface	3.52	.....	2.16		
		3.52	6.98	2.04		
			3.52	6.98	2.10 4.88	-1.36
1910	Surface	3.36	7.10	2.98		
		3.48	7.58	2.67		
			3.42	7.32	2.82 4.50	-1.08

TABLE 2—Continued

Ohle anomaly data

		1	2	3	4	5
		Winkler	Ohle plus Winkler	Ohle only	Corrected Winkler 2-3	Anomaly 1-4
Galveston Bay August 22, 1962	Station 1	3.3m	3.43 2.30	6.60 5.70	2.74 2.57	
			2.86	6.15	2.65 3.50	—0.64
		6.1m	0.48 1.34	4.56 5.23	2.78 2.74	
			0.91	4.89	2.76 2.13	—1.22
	Station 2	9.1m	1.96 0.59	3.86 4.50	2.91 2.81	
			1.27	4.18	2.86 1.32	—0.07
		0755	6.06 5.30	9.12 8.92	3.49 3.55	
			5.63	9.02	3.52 5.50	0.10
	Station 3	1710	8.55 8.64	12.67 12.67	3.50 -----	
			8.59	12.67	3.50 9.17	—0.58
		0820	5.59 5.78	9.60 9.90	3.56 3.79	
			5.69	9.65	3.67 5.98	—0.29
	Station 4	1730	8.05 7.98	12.50 12.85	3.31 3.17	
			8.01	12.27	3.24 9.03	—1.02
		0840	5.59 5.53	9.70 9.60	3.60 3.71	
			5.56	9.65	3.65 6.00	—0.44
	Station 5	1750	7.06 6.72	11.52 10.56	3.36 -----	
			6.89	10.55	3.36 7.19	—0.30
		1810	7.74 7.79	11.25 11.60	3.46 3.07	
			7.76	11.42	3.52 7.90	—0.14
	Station 7	0925	10.55 7.10	10.71 10.93	2.82 3.23	
			8.82	10.82	3.02 7.80	1.02
		1835	7.60 7.82	11.39 11.38	3.25 3.15	
			7.71	11.38	3.20 8.18	—0.47
Nueces Bay October 1-6, 1960	Station 1	1030	4.66 4.84	8.60 8.45	2.91 2.95	
			4.75	8.52	2.93 5.59	—0.84
		2010	4.85 4.85	8.65 9.00	2.91 2.91	
			4.85	8.82	2.91 5.91	—1.06
	Station 2		7.29 7.22	8.81 8.74	2.06 1.88	
			7.27	8.78	1.97 6.81	0.46
			8.23 8.19	9.66 9.61	2.00 1.42	
			8.21	9.63	1.71 7.92	0.29

TABLE 2—Continued

Ohle anomaly data

		1	2	3	4	5
		Winkler	Ohle plus Winkler	Ohle only	Corrected Winkler 2-3	Anomaly 1-4
Station 2b		10.24	11.52	2.89		
		10.32	11.38	2.07		
		10.28	11.45		2.48 8.97	1.31
Station 3		6.19	9.78	3.04		
		7.31	9.76	3.12		
		6.75	9.77		3.08 6.69	0.06
Station 4		6.38	8.22	2.19		
		6.58	8.32	2.11		
		6.48	8.27		2.15 6.12	0.36
Station 6		7.57	9.80	3.10		
		7.55	9.90	3.20		
		7.56	9.85		3.15 6.70	0.86
Station 7		7.55	10.30	3.17		
		7.66	10.27	3.19		
		7.61	10.28		3.18 7.10	0.51
Corpus Christi Bay						
Station 7		5.7	6.8	0.75		
		5.4	6.8	0.70		
		5.55	6.8		0.72 6.06	—0.45
Station 8		6.4	7.0	0.8		
		6.4	7.0	0.7		
		6.4	7.0		0.75 6.25	0.15
Station 9		6.5	6.8	0.6		
		6.8	7.4	0.6		
		6.65	7.0		0.6 6.4	0.25
Station 10		6.2	7.3	0.6		
		6.1	7.0	0.6		
		6.15	7.20		0.6 6.60	0.45
Station 11		6.0	4.8	0.4		
		6.1	6.6	0.8		
		6.0	5.7		0.85 4.85	1.15
Corpus Christi Ship Channel						
September 29, 1960						
Station 1 Bay		6.65	9.12	2.51		
		6.63	9.07	2.72		
		6.64	9.10		2.61 6.59	0.05
Station 2 Corpus Christi Turning Basin		4.17	6.97	2.10		
		4.57	5.32	2.08		
		4.37	6.14		2.09 4.05	0.37
Station 3 Avery Basin		4.36	6.58	2.26		
		4.22	6.54	2.60		
		4.29	6.56		2.38 4.18	0.10
Station 4 Tule Basin		2.18	4.20	0.88		
		2.29	4.40	0.81		
		2.23	4.30		0.84 3.46	—1.23
Station 5 Viola Basin		0.44	2.81	1.73		
		0.53	2.81	1.80		
		0.49	2.81		1.78 1.03	—0.50
Corpus Christi Harbor						
July 21-22, 1962						
Waters were not homogenized first in this series.						
Viola Basin (Station 5)						
0530 Surface		5.43	7.68	6.98		
		6.15	6.14	9.41		
		5.79	6.91		8.14 —1.23	7.02

TABLE 2—Continued
Ohle anomaly data

		1	2	3	4	5
		Winkler	Ohle plus Winkler	Ohle only	Corrected Winkler 2-3	Anomaly 1-4
2000	2.8 m	7.22 6.18	9.27 8.44	6.18 7.79		
			6.70	8.80	6.39 2.41	4.29
	5.7 m	3.65 6.90	2.97 5.57	3.82 6.04		
			5.28	4.27	4.93 —0.66	5.94
	9.5 m	5.19 0	5.23 6.11	0 0		
			2.60	5.68	0 5.68	—3.08
	Surface	4.86 3.72	7.91 9.66	9.26 5.35		
			4.29	8.79	7.31 1.48	2.81
	2.8 m	5.61 2.72	11.16 8.58	3.96 4.08		
			4.17	9.87	4.02 5.85	—1.68
	5.7 m	6.44 6.21	10.01 9.93	6.21 4.61		
			6.33	9.97	5.41 4.56	1.77
Chemical Basin (Station 3b) 0615	9.5 m	2.64 8.74	5.30 10.77	7.22 3.66		
			5.67	8.04	5.44 2.60	3.07
		7.87 3.98	6.56 5.84	5.84 4.65		
			5.43	6.20	5.25 0.95	4.48
	2045	0 0	4.13 6.34	2.46		
			0	5.24	2.46 2.78	—2.78
	Main Basin (Station 2) 0647	6.64 5.24	9.78 5.48	4.59 6.69		
			5.94	7.58	6.09 1.49	4.45
	2131	6.82 8.52	12.90 11.70	5.76 7.01		
			7.67	12.30	6.39 5.91	1.76
	Corpus Christi Bay (Station 1 in Fig. 7) 0722	11.55 8.08	8.98 12.58	10.97 9.97		
			9.81	10.78	10.47 0.31	9.50
1745		7.86	10.47 10.72	4.95 4.78		
			7.86	10.59	4.86 5.73	2.13
	Conn Brown Harbor July 10-11, 1962 0605	7.00	10.68	4.56	6.12	0.88
	1035	9.95	12.97	3.82	9.5	0.80

were also obtained which indicated that a near zero oxygen tension was in the water during the night and morning hours. From the molar ratio of carbon and oxygen changes, assimilatory quotients were computed for each hour. The action of the anaerobic system in putting oxygen and carbon-dioxide changes out of phase and in masking the

oxygen production, produced very different quotients over a short time period (Fig. 9) than those normally found in an aerobic ecosystem (Beyers, 1963), or in single kinds of metabolic processes.

If the rate of change graph for oxygen is plotted without any correction a very large photosynthetic quotient results (3 to 30 moles CO_2 /mole oxygen, see Fig. 9). The Mancy-Okun electrode did not show any oxygen getting through the membrane until late in the morning, but the Ohle analyses implied that substances were present in the water capable of interfering with the Winkler test. In the rate graphs of Fig. 9, an Ohle correction was applied even though there was no assurance that it should be applied before oxygen appears in the Winklers.

For the purpose of computing rate of oxygen metabolism, the Ohle correction may be considered as "negative oxygen" during the period between sunrise and the time of appearance of oxygen in the regular Winkler. The reduced substances which tend to reduce oxygen as fast as it is formed may also provide an Ohle reducing anomaly. In Fig. 9, the adding of the Ohle average anomaly corrects the Winklers upward and converts the negative oxygen to fictitious positive oxygen for the purpose of computing the rate of change graph for oxygen metabolism. The resulting graph is plotted and the molar ratio of CO_2/O_2 becomes more like that expected from photosynthesis and respiratory metabolism.

The course of respiration rate of oxygen varied from a minimum before dawn and a maximum after sunset when oxygen tensions were still high. Respiration during the afternoon was presumably high since oxygen tensions were highest and recent photosynthesis had accumulated labile organic matter.

Whether one makes special computations like that in Fig. 9 or not, it is certain that the metabolism of carbon dioxide and oxygen are not concurrent in systems with night-time anaerobic phases. Respiratory and photosynthetic quotients over short periods of time may take a wide range of values. With parts of the shallow system storing reduced substances as oxygen deficits that are made up later in the day, there is a tendency for carbon metabolic values to be higher and more representative of the total biological metabolism of organic matter. The high AQ and RQ values obtained in other studies (Park et al., 1958; Wilson, 1963) may reflect these processes of delayed oxygen respiration and asymmetric carbon and oxygen processes in various degrees.

Before dawn, the oxygen tensions were close to zero, but the system was not anaerobic in its upper layer and the blue-green algal mat was not operating without oxygen, for there was a steady reaeration influx. The graphs when corrected for the diffusion using the constant from other shallow bays show a considerable respiration (Fig. 9).

The inflowing briny bleedwaters (station 3, Fig. 8) and the lagoon system were high in phosphorus (Table 3 and Fig. 8). These data indicate phosphorus levels much higher than in the Upper Laguna Madre (Odum and Wilson, 1962) into which the bleedwater lagoon drains. Phosphorus in another bleedwater pit near Ingleside July 11, 1961, was 206 ppb.

MEXICAN LAGUNA MADRE—A NATURAL BRINEWATER

For comparison with the bleedwater-bluegreen abnormal system produced by hot saline bleedwaters discharging into the Texas Laguna Madre, measurements were also made in similar depth in the Laguna Madre of Mexico where briny conditions are produced by the natural climatic conditions. Graphs of diurnal oxygen are given for two

stations and two seasons in Fig. 10 as obtained by Mr. Norman Vick, Mr. Robert Lawler, and Dr. Henry Hildebrand from the Mexican Laguna.

The waters of La Capia at 121‰ on May 10, 1961 had no appreciable Ohle interference. Winklers were zero; Winklers plus Ohle reagent 0.98; 0.92; Ohle without manganous inons was 0.95; 0.98. pH ranged from 7.5 to 7.8 without much pattern in the diurnal record.

Apparently the very high salinities, 50 to 121‰, favor nearly anaerobic conditions.

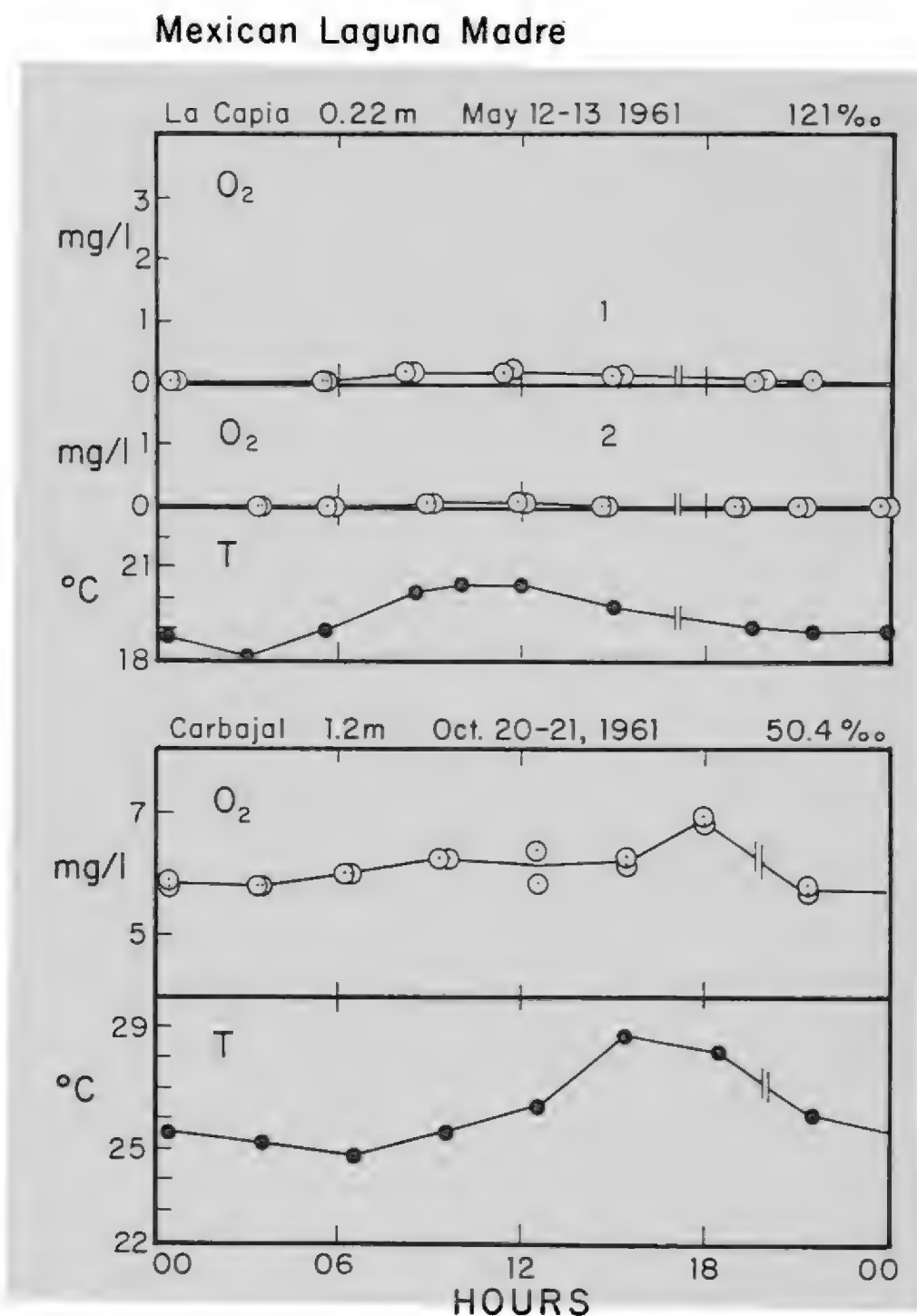


FIG. 10. Diurnal records of oxygen and temperature from the Laguna Madre of Mexico May 12-13, 1961 (Data taken by N. Vick, R. Lawler, and H. Hildebrand) and Oct. 20-21, 1961 (Data taken by R. S. Jones).

Brines have a saturation oxygen tension as low as 1 mg/liter. With the exclusion of many normal animals and other consumers, organic matter added by streams or by photosynthesis can develop high concentrations with water evaporation favoring some microbial decomposition. Some photosynthesis or photochemical liberation of oxygen was observable, but unlike the bleedwater lagoon total metabolism was small.

Also given in Fig. 10 is a diurnal oxygen graph further south at Carbajal opposite

the eighth Pass when salinities were 50.4‰. Although no more saline than the very fertile water of the Texas upper Laguna, the graph in Fig. 10 indicates a very small metabolic amplitude (P, 2.0 g/m² per day; R, 1.2 g/m² per day). Waters were very turbid with suspended clays.

Total phosphorus values in the hypersaline Mexican Laguna Madre, May 11–13, 1961, were relatively high (Table 3).

TABLE 3
Total phosphorus for abnormal marine systems

Location	Date	Station	Total phosphorus in ppb
Bleedwater-bluegreen system	July 25, 1961	1	142, 124, 111, 101
		2	112, 32, 26, 41
		3	378, 778, 543, 876
Mexican Laguna Madre	May 11, 1961	Los Flores	62, 62
		La Capia	127, 119
		Los Ciciones	18, 20
		Arroyo El Tigre	78, 76
		Brackish water arroyo	63, 64
		Arroyo Del Gomeno	496, 500
		Arroyo La Seca	195, 191
	May 13, 1961	Los Flores	180, 186
		La Capia	59, 57
		Los Ciciones	98, 95
		Brackish water arroyo	471
	Oct. 21, 1961	Carvajal	34
Seafood Waste System, Conn Brown Harbor	March 10–14, 1961	1	86
		2	110
		3	98
	June 20, 1961	1	260
		2	88
		3	53
	Aug. 15, 1961	1	189
		2	151
		3	87
Lower Galveston Bay	July 15–19, 1961	1	494, 500
		2	1116, 1302
		5	2000 +
		6	1222, 1295
		7	830, 890
		8	568, 569
		9	431, 488
		10	487, 497
		11	385, 346
		12	298, 345
Upper Galveston Bay	April 18–19, 1961	1	215
		2	8
		3	178, 315
		4	4, 19
		5	112
Corpus Christi Harbor	Jan. 9, 1961	2	1000, 213
		3	273
		4	252
		5	296
	March 6, 1961	2	104, 106, 114, 108
	March 20, 1961	2	119, 119
	April 22, 1961	2	176, 27
	May 22, 1961	2	219, 280, 329, 339

TABLE 3—Continued
Total phosphorus for abnormal marine systems

Location	Date	Station	Total phosphorus in ppb
Nueces Bay	June 12–13, 1961	2	214, 157
		3	380, 325
		4	364, 372
		5	312
	Aug. 8, 1961	1	170
		2	161
		3	146
	March 3, 1961	5	283
		1	9, 6, 10
		2	64, 150, 155
		3	29, 144, 148
Corpus Christi Bay	Aug. 3, 1961	6	97, 4
		1	126, 132
		2	136, 120
		3	98, 114
	March 6, 1961	5	92, 110
		6	118, 115
		8B	8, 8, 11
		9	96, 97, 103
	March 20, 1961	10	113, 114
		11	56, 57, 19, 20
		7	86, 88, 162
		8	6, 14
	April 22, 1961	9	78, 130
		10	74, 75
		7	175, 69
		8B	17, 27
	May 22, 1961	9	8, 4
		11	59, 3
		1	138, 128
		2	142, 144
	Aug. 8, 1961	3	158, 157
		4	184
		7	506, 524
		8B	306, 329
		9	230, 232
		10	228, 220
		11	134, 140
		1	74, 64, 128
		2	63, 78, 84, 100
		3	66, 66, 124
		4	70, 61, 178, 151
		5	61, 39, 52, 78
		7	299, 268
		8	208, 284
		8B	151, 141
		9	170, 152
		10	229, 112

II. SEAFOOD WASTE SYSTEMS

Conn Brown Harbor, Aransas Pass, Texas

In Figs. 3 and 11–18 are presented maps of station data and diurnal curves for Conn Brown Harbor, Aransas Pass, Texas, including three stations, different seasons, and different levels. The basin was artificially produced by a spoil bank formed from dredging (Fig. 2) and lined with shrimp boat docks and food processing plants. Fifty to 400 shrimp boats were present in the basin and refuse from crab and shrimp loading and

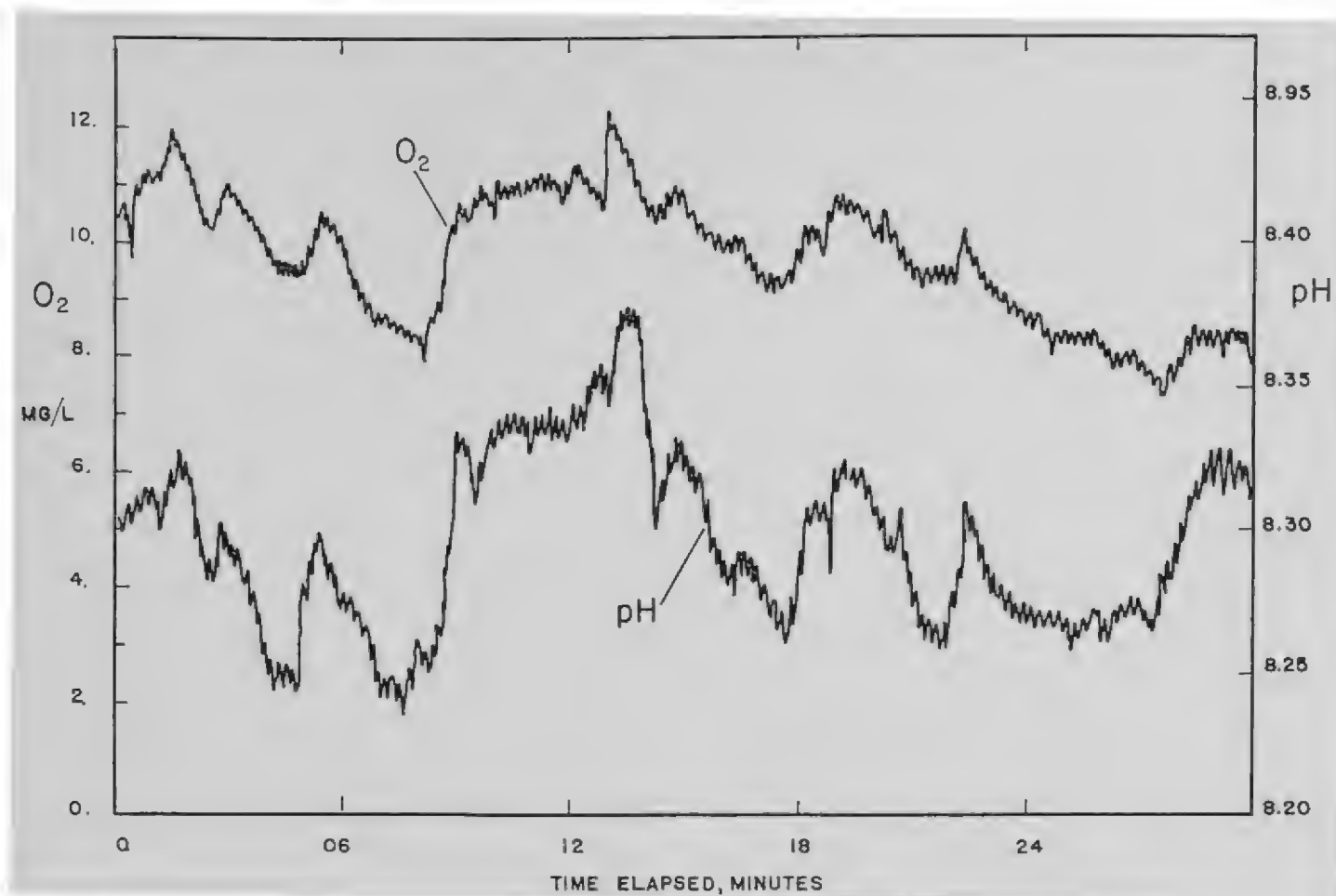


FIG. 11. Dual Channel recorder trace of a Mancy-Okun electrode for oxygen and a Beckman Model W pH meter, both operating on a pumped stream of water in a moving small boat in Conn Brown Harbor during the afternoon, Dec. 3, 1961.

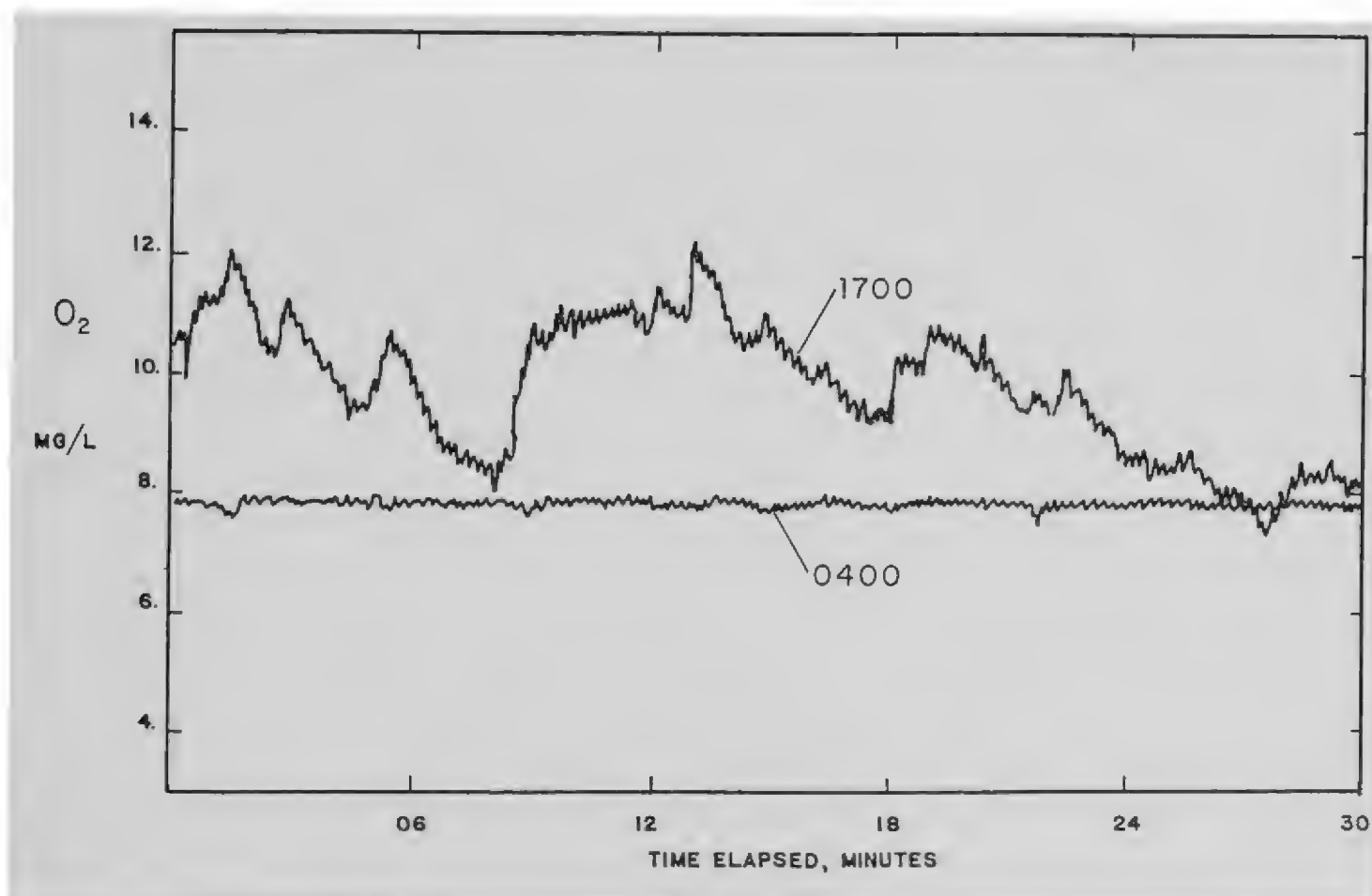


FIG. 12. Comparison of recorder traces of oxygen with the Mancy-Okun electrode during the afternoon and later at night after vertical surface cooling had produced mixing.

packing were dumped into the water, which was 3 meters deep. Water exchange occurred through the channel entrance at the south end by means of wind and tide induced water levels varying about 0.3 m per day. Appreciable stirring and mixing of water levels was observed in the wake of the many shrimp trawlers which had draughts between 1 and 2.5 m.

At times the basin was mixed fairly well vertically and horizontally as indicated by a comparison of oxygen and temperature data from several levels and stations (Fig. 15). At other times some temporary vertical stratification was observed in the distribution of properties (Fig. 18), and some horizontal differences developed from one end of the basin to the other (Figs. 16 and 17). Variations of oxygen and carbon dioxide concentrations over short distances were indicated in the recorder traces of the Mancy-Okun oxygen electrode and the Beckman pH meter (Figs. 11-13). Figure 11 for the daytime showed partial thermal stratification with patchy patterns of waste and heterogenous

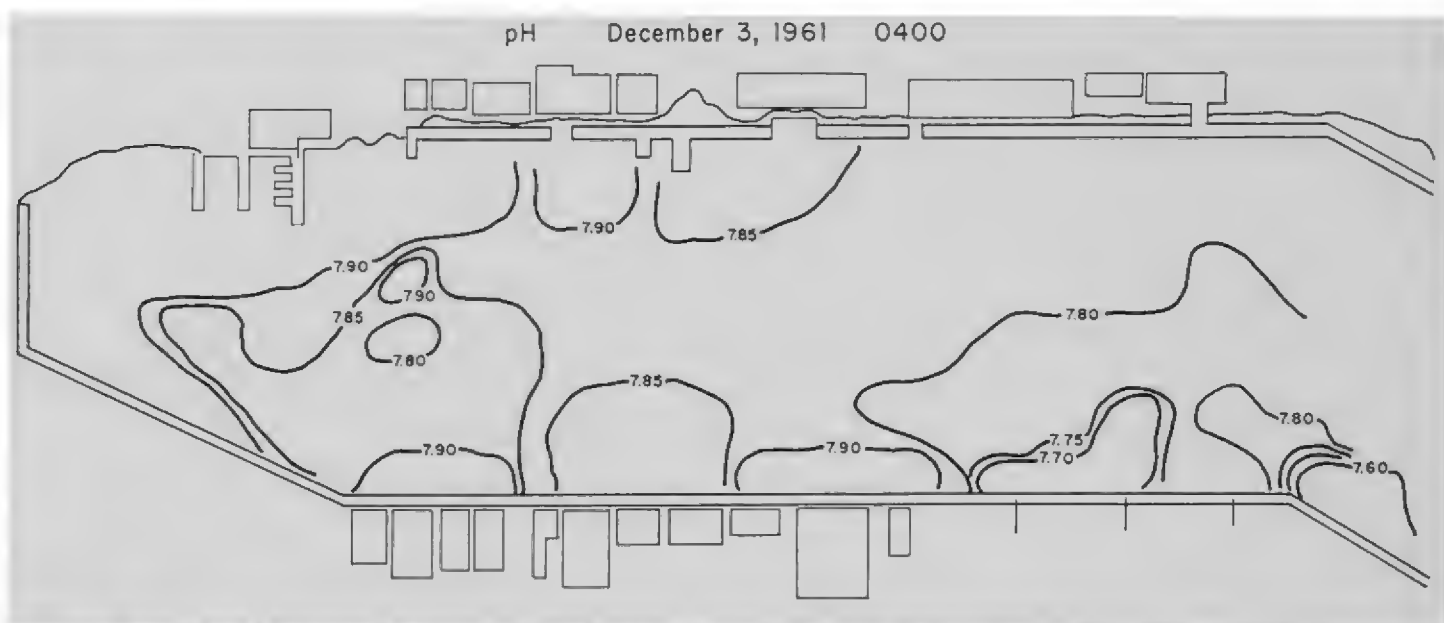


FIG. 13. Horizontal map of pH in Conn Brown Harbor as measured at 0400, Dec. 3, 1961.

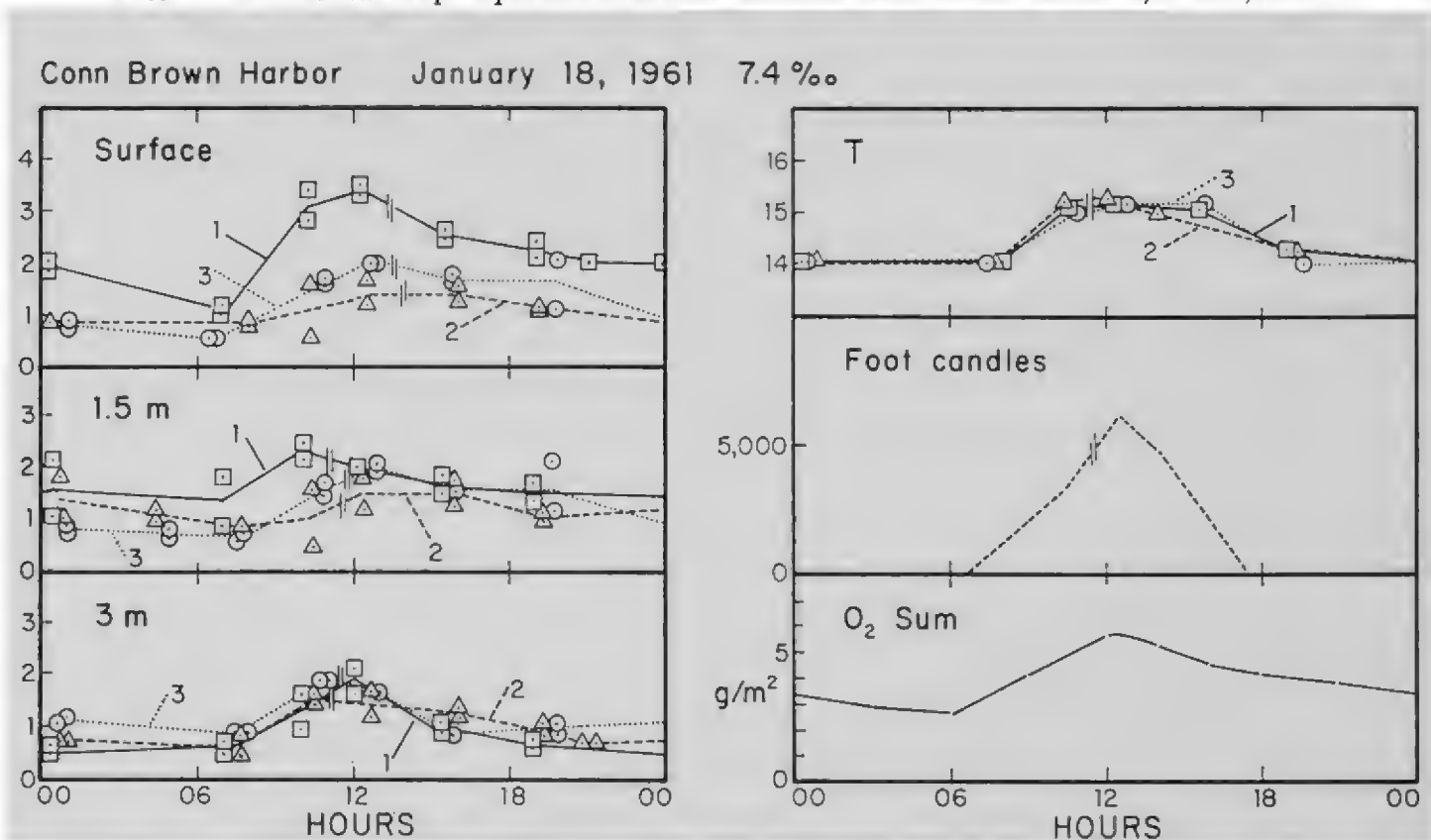


FIG. 14. Diurnal record of oxygen at three stations and three depths in Conn Brown Harbor, January 18, 1961. Data on temperature, light, and the sum of the 9 oxygen curves are plotted.

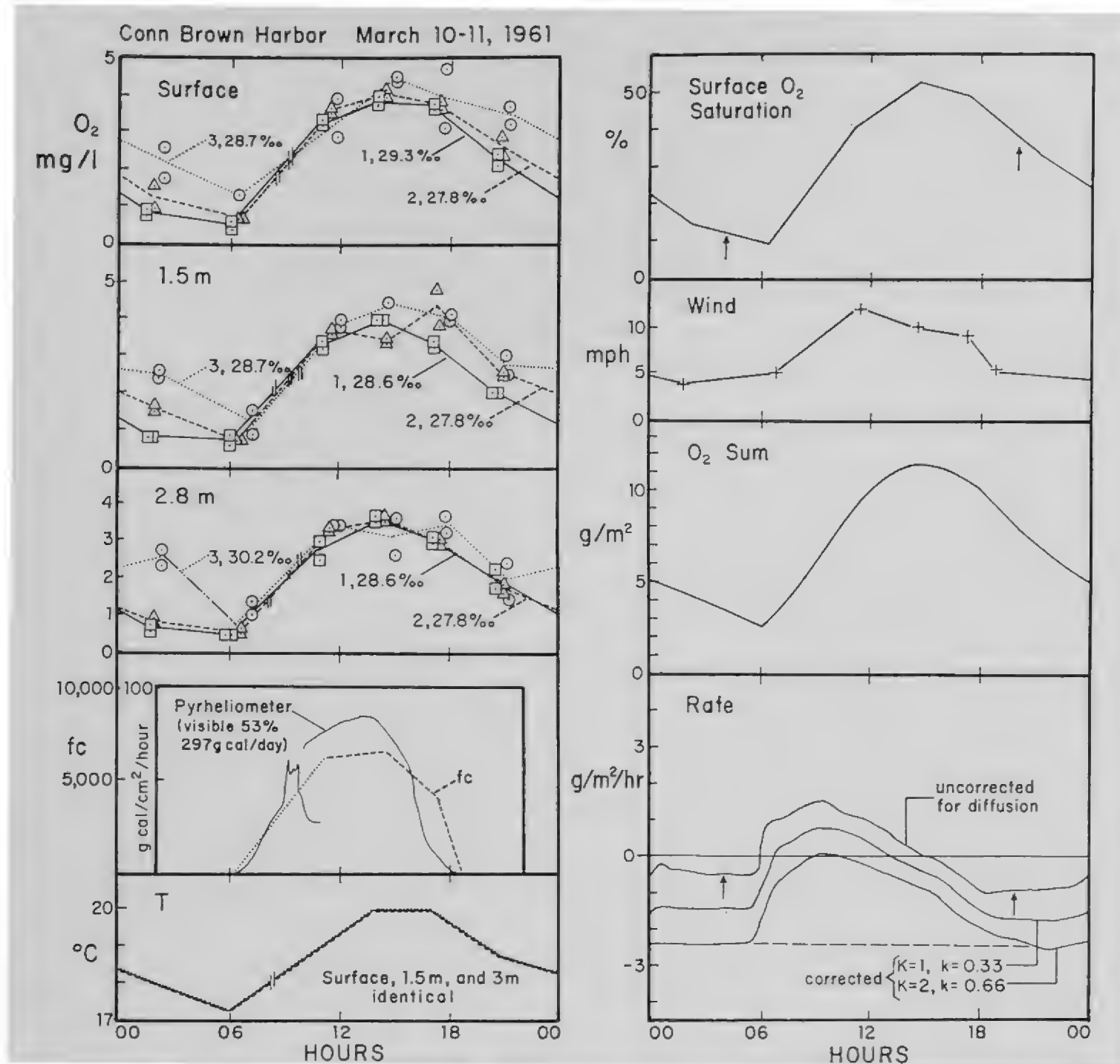


FIG. 15. Diurnal record of wind, light, temperature and oxygen, in Conn Brown Harbor March 10-11, 1961. The sum of the 9 oxygen curves is plotted and used to determine the rate of change. Diffusion corrections for reaeration are made according to two assumptions using the percent saturation curve of the 3 surface curves.

metabolism, whereas at night with cooling at the surface there was better mixing of the basin water (Fig. 12). The dominant role of metabolism in causing patchy variation in properties was indicated by the correlation of pH and oxygen in Fig. 11.

The under-saturated condition of the waters (Figs. 14-17) indicated that the basin often maintained a higher respiration than photosynthesis (see results of metabolism computations in Table 4). At other times (Fig. 18) photosynthesis equaled respiration and diurnal curves were normal although with more amplitude than in less disturbed bays of similar depth, such as Corpus Christi Bay. Only on June 20-21, 1961 (Fig. 16) was metabolism small with irregular patterns of oxygen during the day. Efficiency of utilization of sunlight on this day was only 0.8% of visible energy received.

The highest rate of gross photosynthesis, measured on July 10-11, 1962, was 42 g oxygen per m² per day, with a corresponding efficiency in conversion of visible light energy at 3.8%. This value is as high as that observed in the undisturbed turtle grass beds outside the basin in Redfish Bay (Odum, 1963).

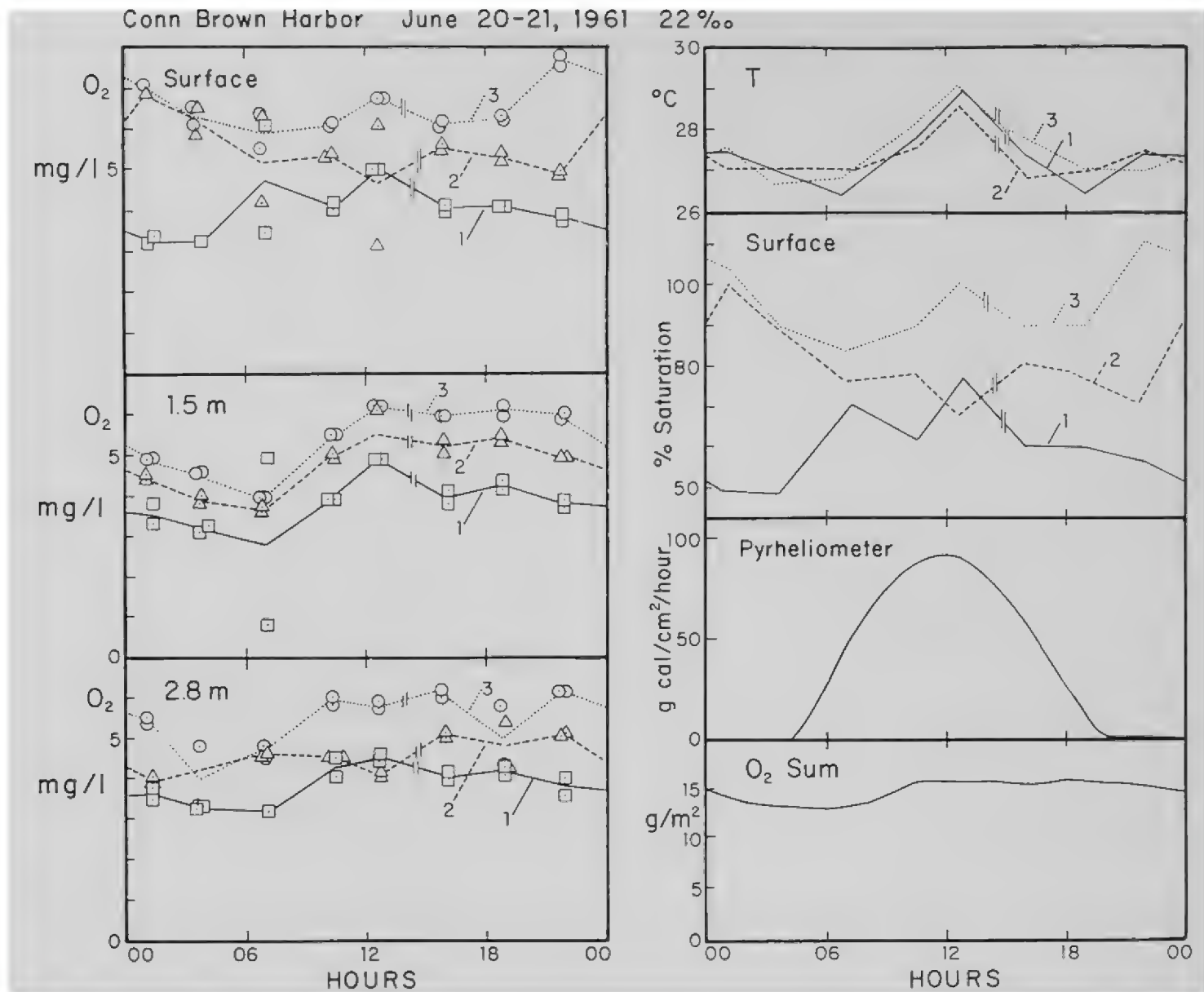


FIG. 16. Diurnal record of oxygen, light, and temperature on a clear day June 20-21, 1961. The sum of the oxygen data is also plotted for the basin.

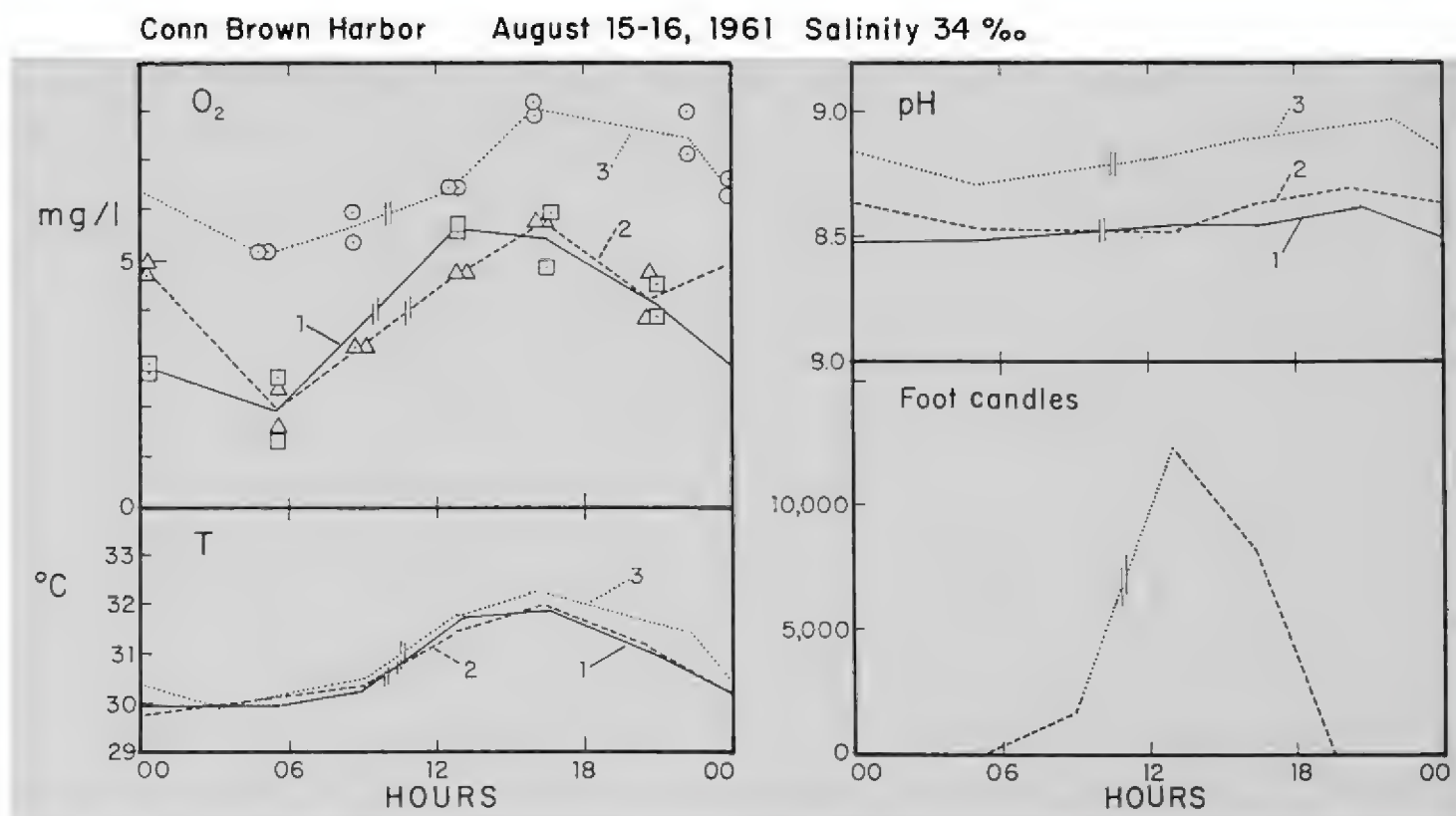


FIG. 17. Diurnal record of oxygen, pH, light, and temperature in Conn Brown Harbor August 15-16, 1961.

TABLE 4
Metabolism in abnormal marine systems

	Number of stations averaged	Depth m	Salinity ‰	T°C	g/m ² per day Oxygen metabolism		g/m ² per day Carbon metabolism		CO ₂ /O ₂		Efficiency† %
					P	R	P	R	AQ	RQ	
Bleedwater-bluegreen system											
July 25-26, 1961											
Station 1	1	0.43	52.5	23-36	6.1	14.3	9.2	6.7	4.0	1.24	....
Station 2	1	0.20	52.5	26-36	7.9	8.7	10.3	10.0	3.5	3.1	....
Station 3*	1	0.64	66.8	33-40	0.9	15.4	3.4	†	10.0	†	....
July 26, 1961											
Station 1	1	0.10	55-60	25-31	1.96	3.5	3.4	3.5	4.8	2.6	....
Nueces Bay											
July 30-31, 1959	1	0.25	15.2	28-37	2.7	2.2	....	....	....	....	....
July 16-17, 1960	2	0.45	34.6	29-33	9.2	4.3	....	....	....	....	....
Oct. 5-6, 1960,	6	0.5	31-36	24-29	6.6	9.0	....	....	....	....	....
Nov. 1-2, 1960, 6 station mean	6	1.0	0.6-0.8	20-23	11.7	14.4	....	....	....	....	....
June 26-27, 1961	4	0.92	8-26	27-30	0.5	3.2	....	....	....	....	0.05
Aug. 3-4, 1961	5	0.78	13-18	27-32	4.7	7.5	....	....	....	....	....
Seafood Waste System, Conn Brown Harbor											
Jan. 17-18, 1961	3	3.0	7.4	14-15	4.0	5.0	....	....	....	....	....
March 10-11, 1961	3	3.0	27-30	17-20	15.0	17.0	....	....	....	....	2.0
June 8-9, 1961	3	3.0	21.0	28-29	15.0	17.0	....	....	....	....	2.1
June 20-21, 1961	3	3.0	22.0	27-29	8.0	12.0	....	....	....	....	0.8
Aug. 15-16, 1961	3	3.0	34.0	30-32	18.0	23.0	....	....	....	....	....
July 10-11, 1962	3	3.0	33.0	29-33	42.0	35.0	40.0	48.0	0.7	1.0	3.8
Corpus Christi Bay											
May 24-25, 1961	5	4.0	25-28	24-27	21.6	48.0	....	....	....	....	....
Dec. 28-29, 1961	4	4.0	12-15	26-27	1.3	1.3	....	....	....	....	....
June 19-20, 1961	5	4.0	25-27	27-29	14.0	27.0	....	....	....	....	1.9

* Inflowing hot bleedwater station.

† Possible CO₂ diffusion of importance.

‡ Efficiency of gross photosynthesis computed as 4 KCal per gram of oxygen production output and 50% of pyrhelimeter records taken as available input.

In the series taken July 10–11, 1962 (Fig. 18) a comparison was made between the oxygen and radiocarbon bottle methods for measuring production and the diurnal free-water oxygen and pH methods in the highly productive plankton-type system existing at that time. Per area, daily gross production in free water was 1.3 moles for oxygen and 0.9 moles for carbon dioxide. In bottles oxygen production was 0.47 moles while radiocarbon fixation was about 1.4 moles, although bottles were variable. Examinations of the plankton at this time indicated a dominant phytoplankton of small green flagellates and minute diatoms. The zooplankton was dominated by *Acartia tonsa*, a species of *Olithona*, and pelecypod larvae. In March, 1962, the zooplankton contained mainly *Acartia tonsa*, *Centropages*, barnacle larvae and zoeae larvae.

In Fig. 3 and Table 3 are given total phosphorus analyses (mean of paired samples) for Conn Brown Harbor and adjacent waters. High phosphorus values (averaging 143 ppb) were found in the harbor as compared to the outside waters (49 ppb) over the turtle grass beds where most of the nutrients of the ecosystem were bound into benthic components.

The zooplankton species diversity of the outside bay waters (Fig. 3) averaging 14 species per 1000 individuals decreased to about 6 species per 1000 in the north end of the harbor.

BROWNSVILLE CHANNEL

Shown in Fig. 4 are data for the Brownsville shrimpboat channel which extends from the open Gulf westward through jetties, the Lower Laguna Madre of Texas, and through a dredged 3–4 m channel to the city of Brownsville. In depth, in aspects of restricted circulation, and in frequency of shrimp boats, this channel resembles Conn Brown

TABLE 5

Light and dark bottle measurements for oxygen* in Conn Brown Harbor based on triplicates, g/m³

Depth	I Start	D Dark	L Light	P gross (L-D)		R (I-D)	
				6 hrs	12 hrs	6 hrs	24 hrs
0.5	4.49	2.85	8.70	5.85	11.70	1.64	6.56
2.0	4.49	2.39	2.86	0.47	0.94	2.10	8.40
3.0	5.25	2.05	3.16	1.11	2.22	3.20	12.80
3 m column per day:					14.86 g 0.47 moles		27.76 g 0.86 moles

* Ohle correction anomaly was 0.84 mg/l oxidizing (Winklers higher than Ohle-Winkler); See Table 2.
Values above are uncorrected.

TABLE 6

Radiocarbon measurements of productivity in 50 ml. bottles in Conn Brown Harbor from noon to 6 p.m., July 10, 1962

Sample	Counts per minute	Mean photosynthesis moles/m ³ /6 hrs.
Starting water	2921†	-----
0.5 m, 6 hrs	1990, 1780, 362	0.53
2.0 m, 6 hrs	668, 111, 308	0.14
3.0 m, 6 hrs	64, 84, 152	0.04
Sum, 0–3 m, 24 hrs	-----	1.4 moles/m ²

* Dark absorption subtracted.

† Inorganic carbon, 0.056 millimoles per 50 ml.

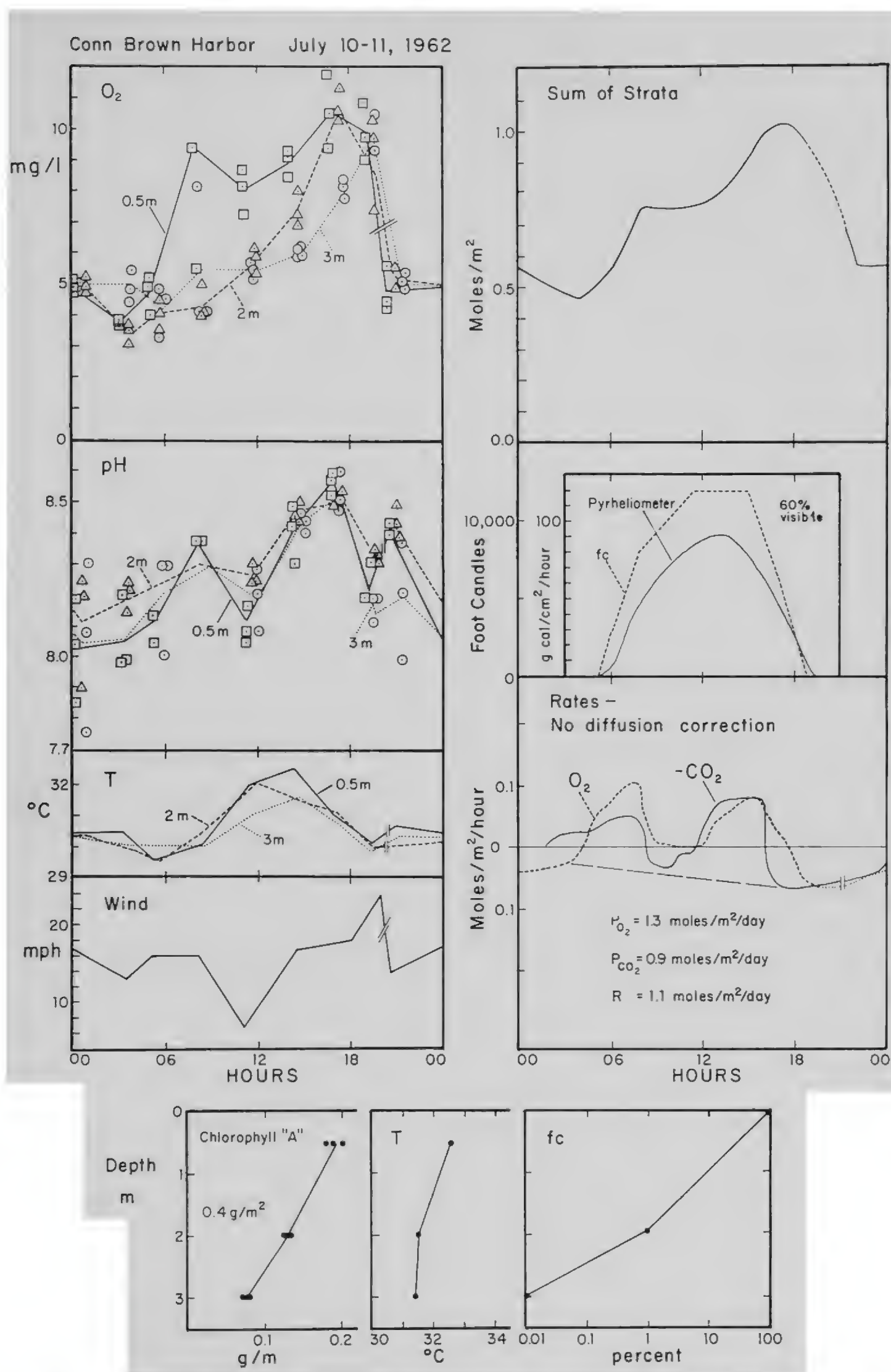


FIG. 18. Diurnal record of variables at three levels in Conn Brown Harbor July 10-11, 1962. From the sum of data, rates of photosynthesis and respiration are plotted. Vertical patterns of light, temperature, and chlorophyll "A" are plotted indicating some stratification.

Harbor at Aransas Pass. Disposal of wastes from seafood processing was dispersed over a much longer channel than at Aransas Pass. The general ecology of the lower Laguna area was described by Breuer (1962). However, the bay waters at Port Isabel are less disturbed by seasonal and rainfall variations than further north; Gulf of Mexico waters flow inward much of the year.

The waters in the jetty were characterized by high species diversities (15 to 32 species per thousand individuals); low phosphorus contents; and the typical fairly high salinities of the open Gulf. In the inner sections of the channel lower species diversities were observed (8 to 18 species per thousand), and somewhat higher phosphorus values. On July 3, 1961, 68 ppb was found at Port Brownsville, and 40, 22 and 58 ppb in samples in the lower Laguna Madre near Port Isabel. On Aug. 16, 1961, 84 ppb was found at Port Brownsville and 39, 81 and 47 in the lower Laguna near Port Isabel.

III. CHANNELS AND BAYS RECEIVING WASTES FROM INDUSTRIAL COMPLEXES OF OIL CITIES

Houston Ship Channel

As documented by Chambers and Sparks (1959) the Houston Ship Channel extending from Houston to Galveston Bay (Fig. 6) receives many wastes and varies widely in oxygen, salinities, and living components. It is a relatively deep ecosystem much disturbed both by discharges from an oil-based industrial complex and variable river flows.

Chambers and Sparks (1959) showed the great variation in accumulation of wastes during stagnant periods as contrasted with periods when there were strong flows of fresh-water down the San Jacinto River flushing the channel and lowering salinities in the Galveston bay system. Some metabolic data, diversities, and phosphorus analyses are reported here during periods of moderately rapid flushing and low salinity.

Species diversity in zooplankton was low, 4–11 species per thousand individuals, June 14, 1962. Total phosphorus levels were high below the Baytown Tunnel (Fig. 6) on July 16, 1961, with 1222 and 1295 ppb. But during a period of low salinity and flushing, phosphorus in the San Jacinto River was 0 and 13 ppb and in the channel and bays south of the river enroute to Galveston Bay, values were very low: 2, 43, 19, 5 and 11 ppb. Ohle anomalies August 22, 1962, at the Baytown Refinery were reducing, -0.6 to -1.22 ppm.

Diurnal oxygen curves at 3 stations on a cloudy day July 17–18, 1961, were measured from 4 strata as presented in Fig. 6. Oxygen for each of the three vertical columns was summed to obtain a diurnal curve on an area basis. At the time of measurement regular diurnal curves were observed in the surface layers both in oxygen and pH. Data plotted vertically in Fig. 6 suggest some vertical stratification. Because of the possibilities of complex inflows and outflows, the diurnal oxygen changes were not converted into estimates of *in situ* metabolism, but the existence of considerable photosynthesis indicated a viable and productive system during that low salinity period.

Where shallow bays 1 m deep surround boat channels dredged to intracoastal depth of 4 m or ship channel depth of 9 m, some circulatory patterns in the bays can affect the channels. The shallow waters have a higher temperature amplitude so that late at night waters may reach their coldest and maximum density with a tendency to drain into the deeper channels. Since oxygen is also at its minimum late at night, a mechanism

exists for draining low oxygen waters into the bottom of the stratified and partially stratified channels. One cannot, therefore, regard the bottom waters of the channels as old or with low oxygen because of hypolimnetic isolation. Conversely, waters from the shallow bays drifting over the channels during the day may tend to pass without much interchange since at that time temperatures are highest and stratification may persist.

Galveston Bay

In Figs. 5, 19, and 20 are metabolic data for upper and lower Galveston Bay which receive the wastes from the Houston Ship Channel and from other industrial areas on the west side such as at Texas City and Seabrook. The data for July, 1961 (Figs. 6 and 19) were taken when freshwater floods had lowered salinities to 10‰ or less as far as the mouth at Galveston, whereas data in April (Fig. 5) and August (Fig. 20) 1961, were taken when salinities in Galveston Bay were higher.

The separate diurnal curves of oxygen and pH at the several stations in Galveston Bay were plotted separately and since the data indicate differences in the metabolic properties of the water masses, photosynthesis and respiration were computed separately. Oxygen metabolism was plotted in the sketch maps in Figs. 5 and 19. The ratio of carbon metabolism determined with the pH method to the oxygen metabolism was computed and plotted both as AQ (assimilatory quotient for gross photosynthesis) and RQ (respiratory quotient for total community respiration). These metabolic quotients (Fig. 5) were somewhat variable, 0.43 to 1.8. Metabolic quotients for Galveston Bay, July 15–19, 1961 which go with Fig. 19 were as follows: assimilatory quotient CO_2/O_2 , 1.6 at station 10; 1.4 at station 11; 1.0 at station 12; and 4 at station 13; respiratory quotients for nighttime CO_2/O_2 were: 1.7 at station 10; 0.96 at station 11; 1.9 at station 12; and 1.7 at station 13. Most of the diurnal curves were regular in form with dawn minima and late afternoon maxima. Even though the water was fairly deep (2–4 m; see Figs. 5 and 19), the daily amplitude of change was considerable and the resulting metabolic estimates very large, 60 g/m² per day or more.

For August 22–23, 1962 (Fig. 20) all the curves were averaged (except the one for the Houston Ship Channel), and the mean curve was used to compute an overall metabolism of the upper Galveston Bay. Also shown on that day is the diurnal pattern of wind involving evening seabreeze effects. Ohle anomalies for the bay (Table 2) were small and application of the correction (Fig. 20) had little effect on metabolic computations.

In several instances, the diurnal curves for a particular station differed markedly from others nearby. For example, station 12 near Texas City showed absence of metabolic rhythm in both oxygen and pH. Oxygen remained saturated during most of the day (Fig. 19), indicating little photosynthesis, respiration, chemical oxidation reduction or other processes involving oxygen, a rare situation in marine waters of Texas in the summer.

The diurnal curve for station 3 (Fig. 5) near Seabrook was also characterized by smaller daily amplitude than the surrounding stations. The three curves in West Bay (Fig. 19) differed from those taken at the same time in lower Galveston Bay. Data from Galveston Bay (Figs. 5, 19 and 20) were very patchy with a wide range of oxygen values in duplicate points, not usual for a well mixed bay with large fetch and waves. West Bay was more uniform.

Total phosphorus analyses were taken in pairs at different times of day when the

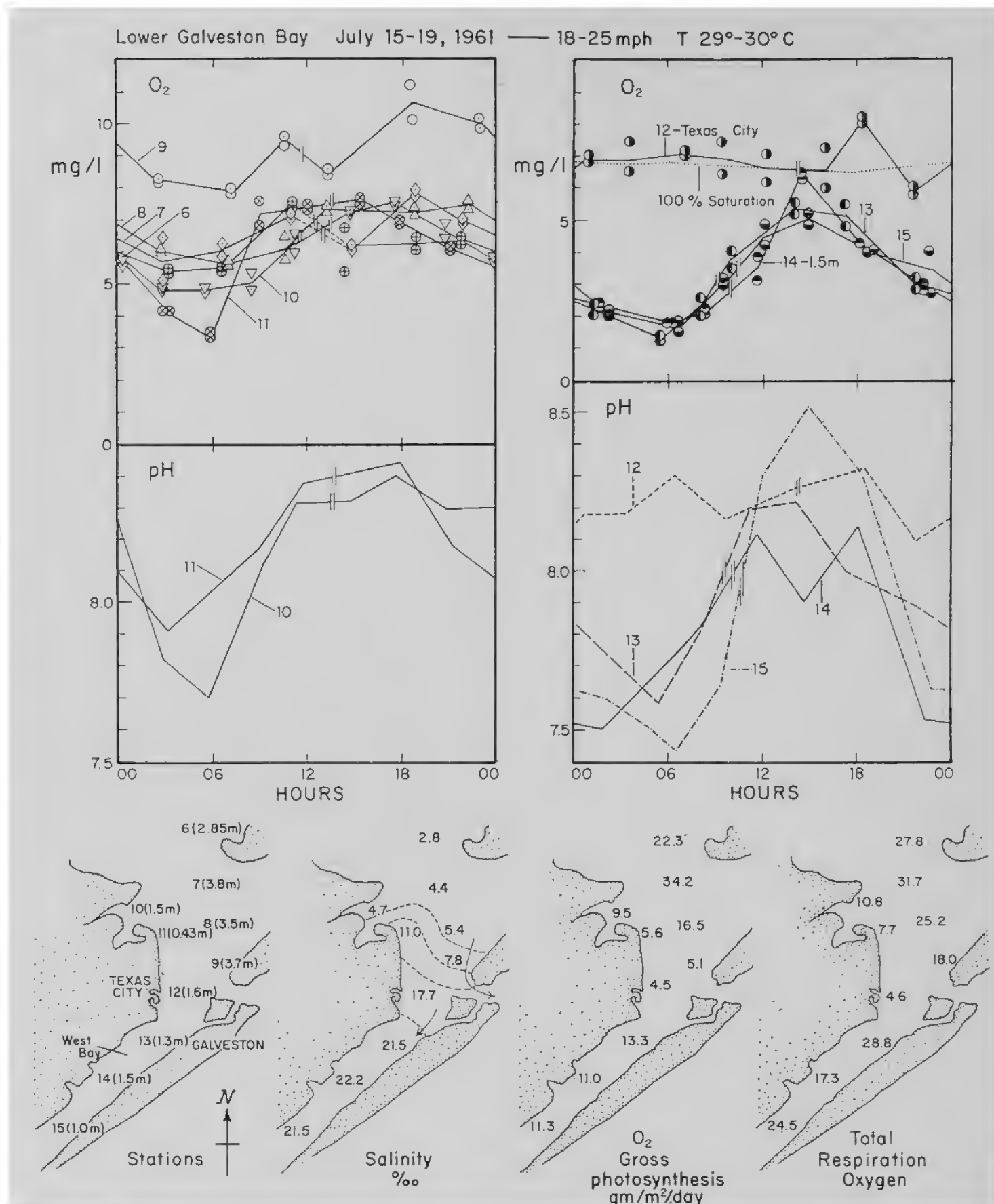


FIG. 19. Distribution of variables and diurnal record of oxygen and pH in lower Galveston Bay, July 15-19, 1961.

July 15-19, 1961, metabolic measurements in lower Galveston Bay were very high (Table 3 and Fig. 19). Values decreased from the upper bay to lower bay. Total phosphorus at some stations in upper Galveston Bay April 18-19, 1961, were also fairly high (Table 3 and Fig. 5). High phosphorus values extended through the Galveston jetties with 182 and 172 ppb Oct. 14, 1961, diminishing in the open Gulf of Mexico. On November 17-19, 1961, a series of phosphorus samples was taken aboard the Texas A&M ship, *Hidalgo*, through the courtesy of Dr. Donald Hood and Dupont Company. Total phos-

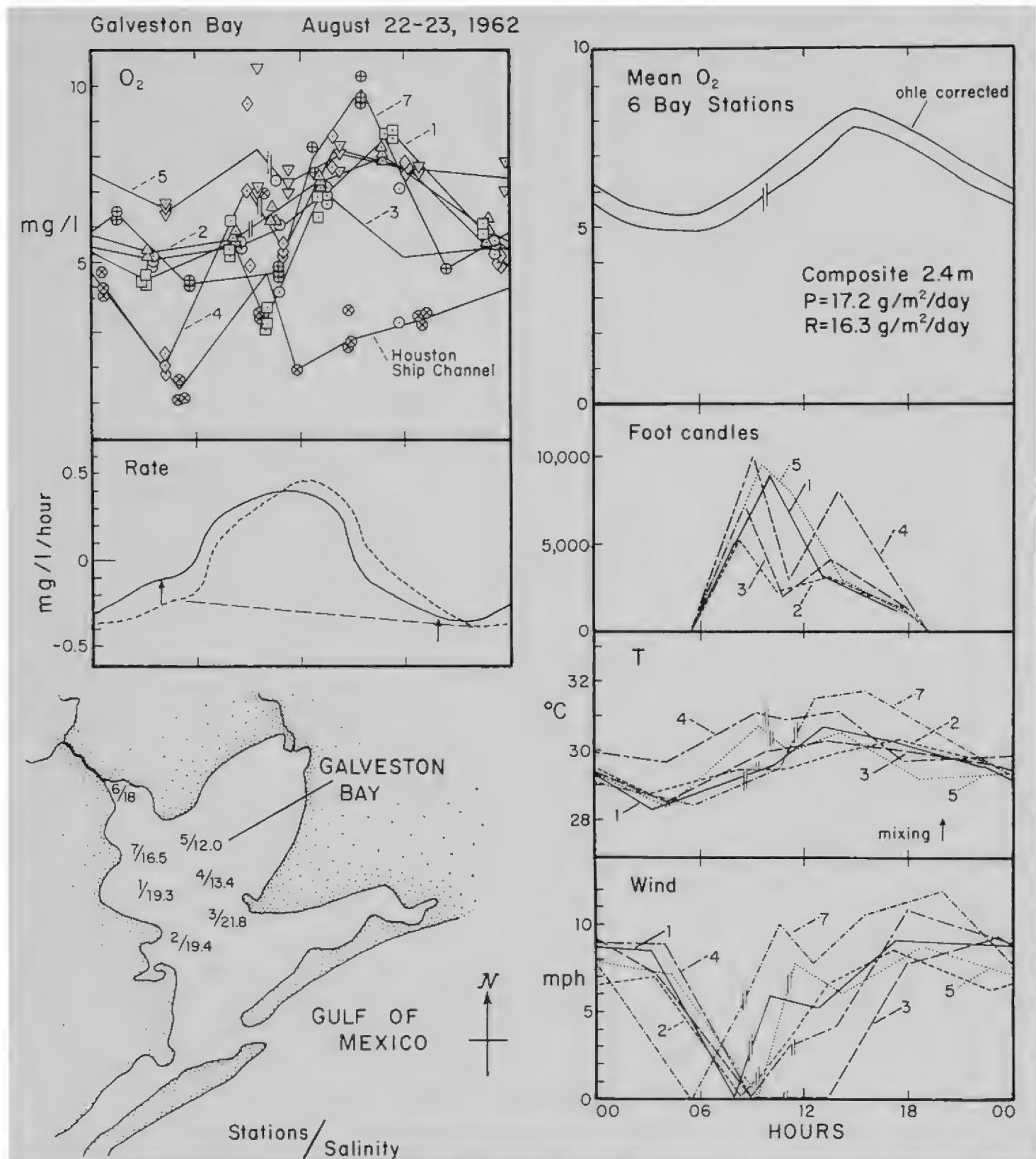


FIG. 20. Salinity distribution and diurnal record of variables at 7 stations in upper Galveston Bay. Metabolic rates and were computed from the composite curve of all bay data. Field data taken with the light-meter are compared for the several stations.

phorus was 112, 107, 93, and 75 ppb in Galveston Harbor, 32, 36, 30 and 54, at the mouth of Galveston jetties, diminishing 50 miles offshore to 14 and 17 ppb at latitude 29°08' N and longitude 93°48' W.

Galveston Bay on August 22, 1961, was characterized by Ohle anomalies of reducing type mainly less than 1 ppm (Table 2) but somewhat higher values were found at a station near Seabrook. Some high values for organic matter were found by Wilson (1963). Low species diversities were found in zooplankton. Species per thousand individuals were few on February 24, 1962, and were as follows: 3 at station 1; 3 at station 2; 3 at station 3; 2 at station 4; 3 at station 5; 3 at station 6; 2 at station 8; 2 at station

9; and 3 at station 10 (mainly *Acartia* and barnacle larvae). On June 14, 1962 there were 4 species per thousand in the Houston Ship Channel at the San Jacinto monument increasing to 6 and 7 in the mouth of the channel south of Baytown. Species diversities were 8, 8, 8, 11, and 9 in upper Galveston Bay, 23 at a station in lower Galveston Bay and 12 at the Galveston jetties. *Acartia tonsa* and barnacle larvae were dominant.

Thus, the waters of Galveston Bay were rich in phosphorus, restricted in species diversity and patchy and variable in metabolism and Ohle anomaly, with some of the highest and lowest rates of respiration observed in Texas Bays in summer.

Corpus Christi Harbor

As shown in Fig. 7, Corpus Christi Harbor is a nearly closed marine arm surrounded by industries. Anderson (1960) lists 2 million gallons per day of industrial wastes entering Corpus Christi Bay, much of it through the harbor and 9 million gallons per day as treated municipal effluent. To the west at station 5, the Viola Turning Basin is adjacent to the Suntime Refining Company; station 4, the Tule Lake Turning Basin is adjacent to the North American Petroleum Corporation and Corn Products Company. In the vicinity of station 3B (chemical turning basin) and station 3 (Avery Point Turning Basin) are Columbia Southern, National Lead, Sinclair Refining, American Smelting and Refining, and Howell Refining Co. Between stations 2 and 3 is located the Central Power and Light Company. Both the Power Company and Columbia Southern draw cooling water from the ship channel and pump it north into Nueces Bay at a combined rate of 155 million gallons per day (Anderson, 1960). East of station 3 are located Pontiac Refinery, Magnolia Petroleum, Haliburton Cement, and several pipe line companies with tank farms. Station 1 was located out in Corpus Christi Bay north of the ship channel where waters were mixing vertically in a depth of 3 m. This station was receiving wastes from Nueces Bay and directly from the harbor depending on current and exchange.

Because of the large pumping rates, waters from Corpus Christi Bay are drawn into the ship harbor to be pumped out into Nueces Bay and eventually back into Corpus Christi Bay again. Nueces Bay also receives Nueces River which varies greatly in flow so that the Nueces Bay salinity varied from less than 1‰ to 45‰ during the period of study. The concentration of wastes thus varied markedly in Nueces Bay.

From the 5 stations indicated in Fig. 7, data on metabolism and diurnal variation of properties are presented for Corpus Christi Ship Harbor in Figs. 21–24.

On Sept. 28–29, 1960 (Fig. 21) the salinity was high (37‰) and all stations were very low in oxygen at all depths. The Ohle anomaly (Table 2) was negligible in the Bay, oxidizing positive at station 2, but up to -1.23 ppm (reducing) in the basin. The diurnal oxygen amplitude in all stations including the bay station was small indicating little photosynthetic metabolism. The undersaturated condition (much more than accounted for by the Ohle reducing anomaly) indicated a rapid respiration and/or chemical oxidation complicated by diurnal changes in temperature stratification. Especially between midnight and 0600 the temperatures at all levels became similar as night cooling caused a turnover. Oxygen increased at night. The mixing was complicated by the very large stirring effect of the many deep-draught ships. Oxygen was lowest in the terminal end of the harbor, Viola Basin.

On June 12–13, 1961, oxygen levels were higher in the main basin and upper waters,

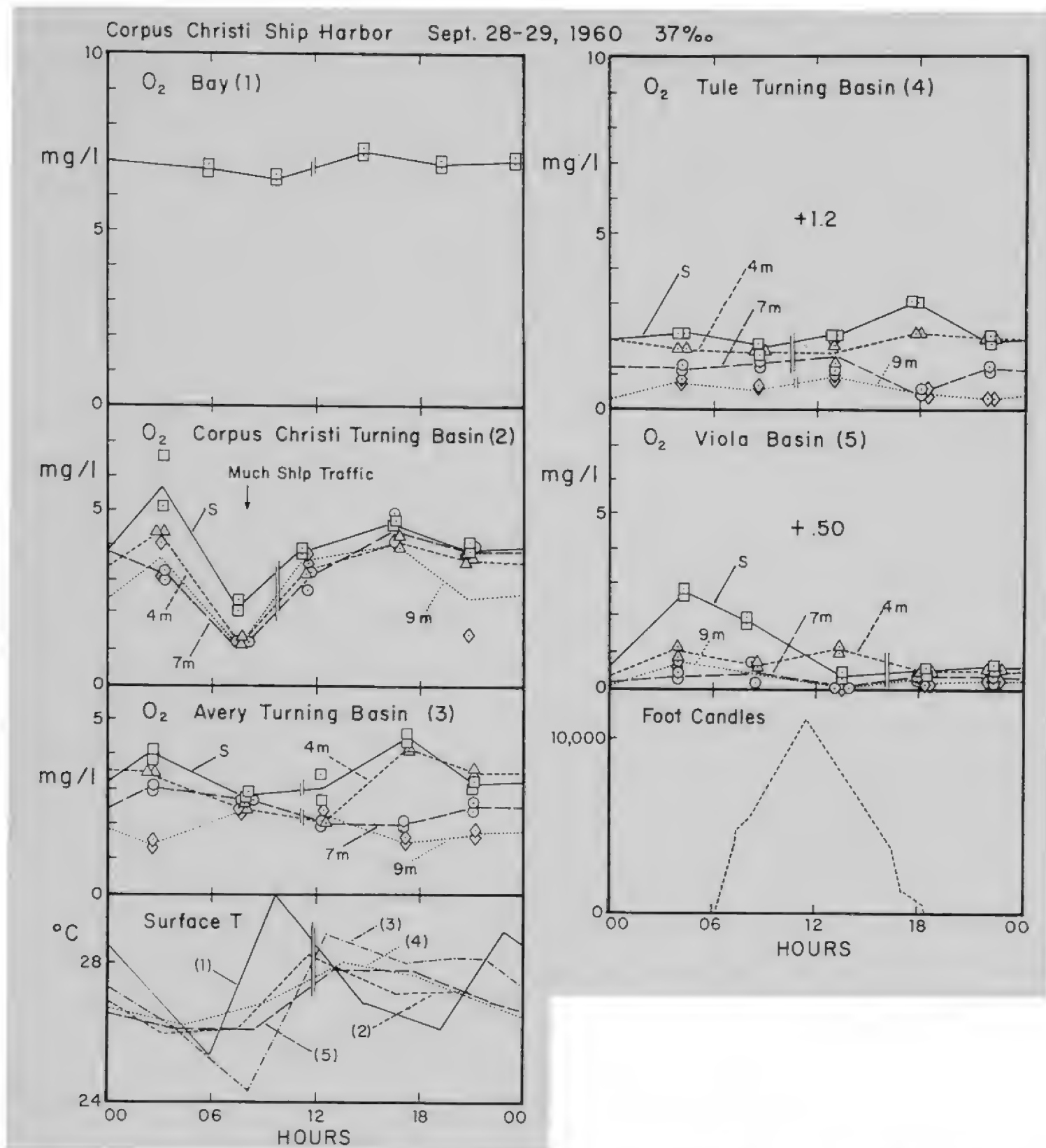


FIG. 21. Diurnal record of variables for 4 depths and 5 stations in the Corpus Christi Ship Harbor, Sept. 28-29, 1960. Ohle corrections are given (+1.2, +0.5) for stations 4 and 5.

although low oxygen water was in the deeper parts of the inner basin where stratification was maintained during the day and night. There was considerable photosynthesis between 0300 and the afternoon. The vertical patterns Jan. 8, 1961, were similar with salinity stratification.

On July 20-21, 1962 (Fig. 24) oxygen and pH measurements were made. The range of variation was very large, completely masking any regular daily pattern of photosynthesis, if present. In the bay outside there was also a large scatter indicating patchy patterns in water trajectory and metabolic state.

At stations 2 and 3B the surface waters were strongly affected by acid wastes dropping pH as low as 5.5. Whereas the Sept. 28-29, 1960, record in Fig. 21 had low oxygen

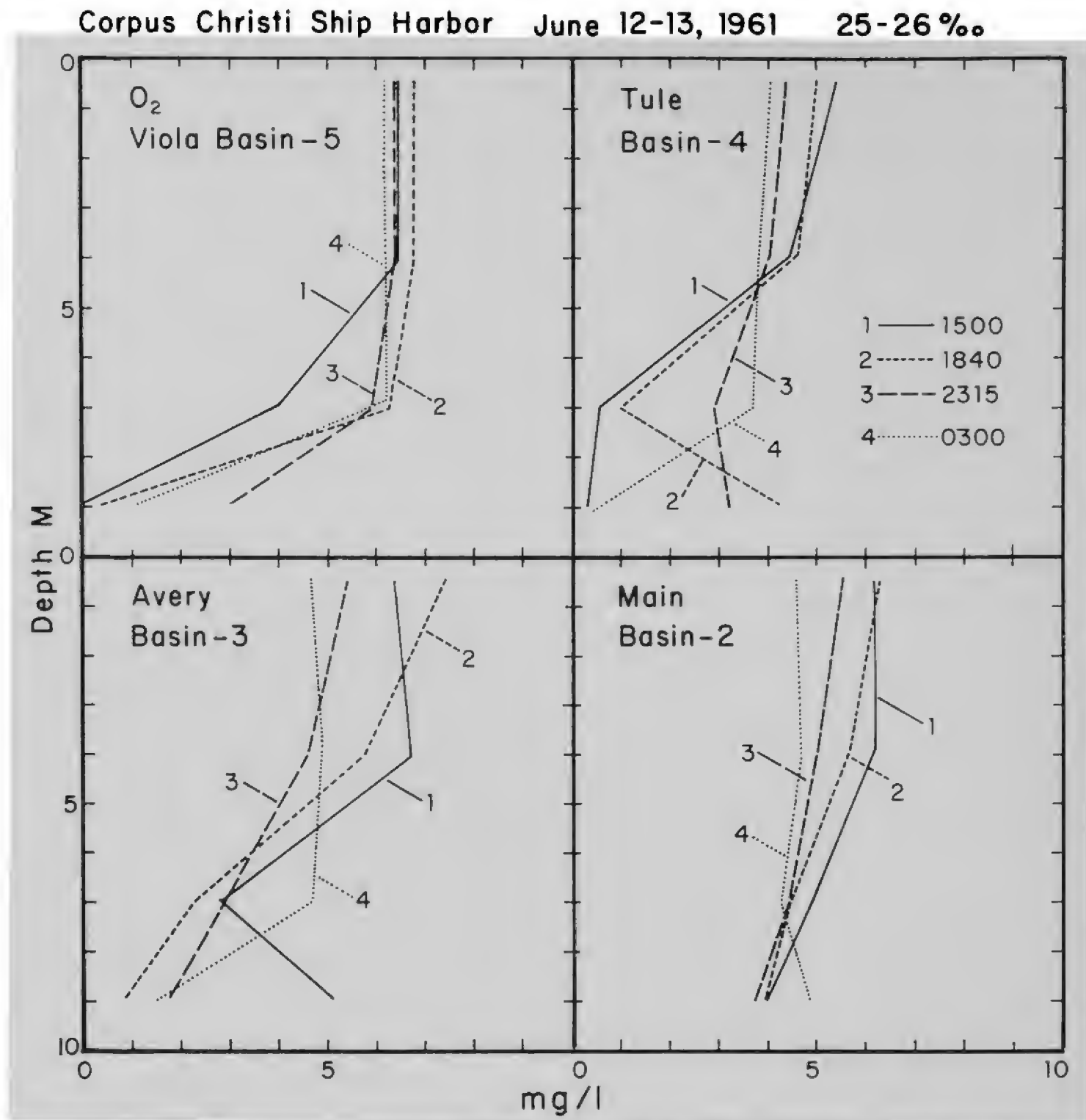


FIG. 22. Vertical pattern of oxygen during the day and night in Corpus Christi Ship Harbor, June 12-13, 1961.

values indicating active respiration, the data in Fig. 24 indicated extreme variation and oxygen not far from saturation at many levels as in the Viola Basin.

The Ohle anomalies for this same week (Table 2) were very large and variable ranging from -3 ppm (reducing) to $+7$ ppm (oxidizing). Thus the highly variable data in Fig. 24 were partly due to the patchy dispersion of both oxidizing and reducing substances. Under such circumstances, accurate metabolic computations could not be made from the diurnal curves, but the oxygen and Ohle data together indicate the presence of strong chemical wastes throughout the system and an interference with uniform gas metabolism.

The species diversity counts in the harbor were lower than in the bay (Fig. 32). Salinities in the harbor during diversity studies in 1962 ranged from 30 to 35‰. On Dec. 6, 1961 and Feb. 17, 1962, no plankton could be found to count in the harbor. Minter

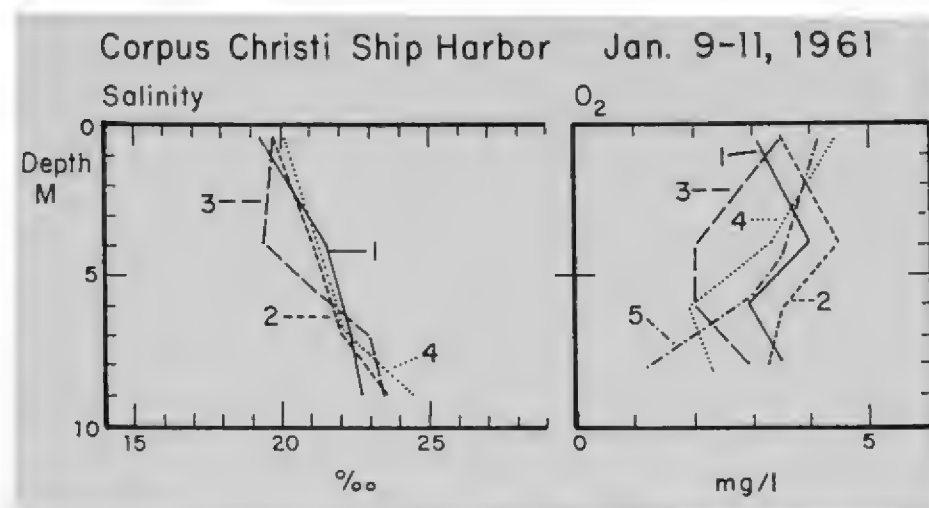


FIG. 23. Vertical patterns of salinity and dissolved oxygen at 5 stations in Corpus Christi Ship Harbor, Jan. 9-11, 1961.

(1963) reported an absence of zooplankton in oil refinery effluent ponds during winter, followed by a low species diversity during summer.

The total phosphorus content in the harbor was highest of all waters in the surrounding bays, enough to be used as a means of tracing water movements (Table 3 and Fig. 7).

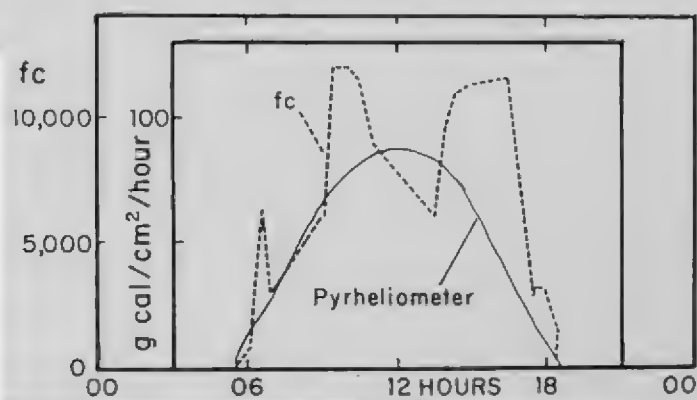
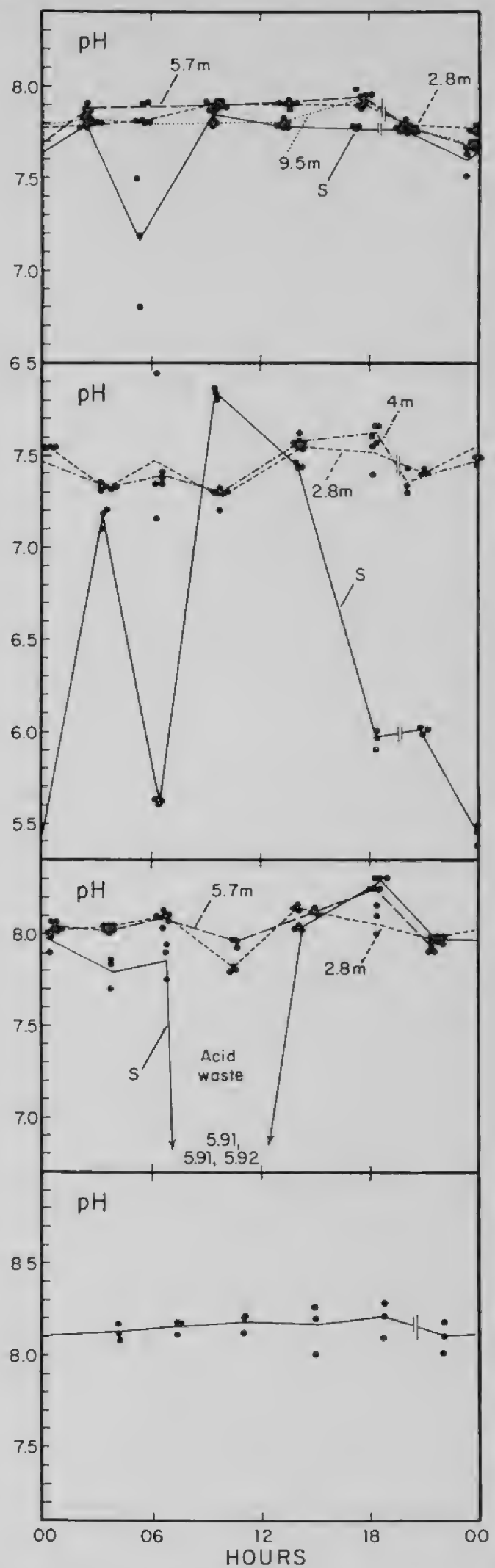
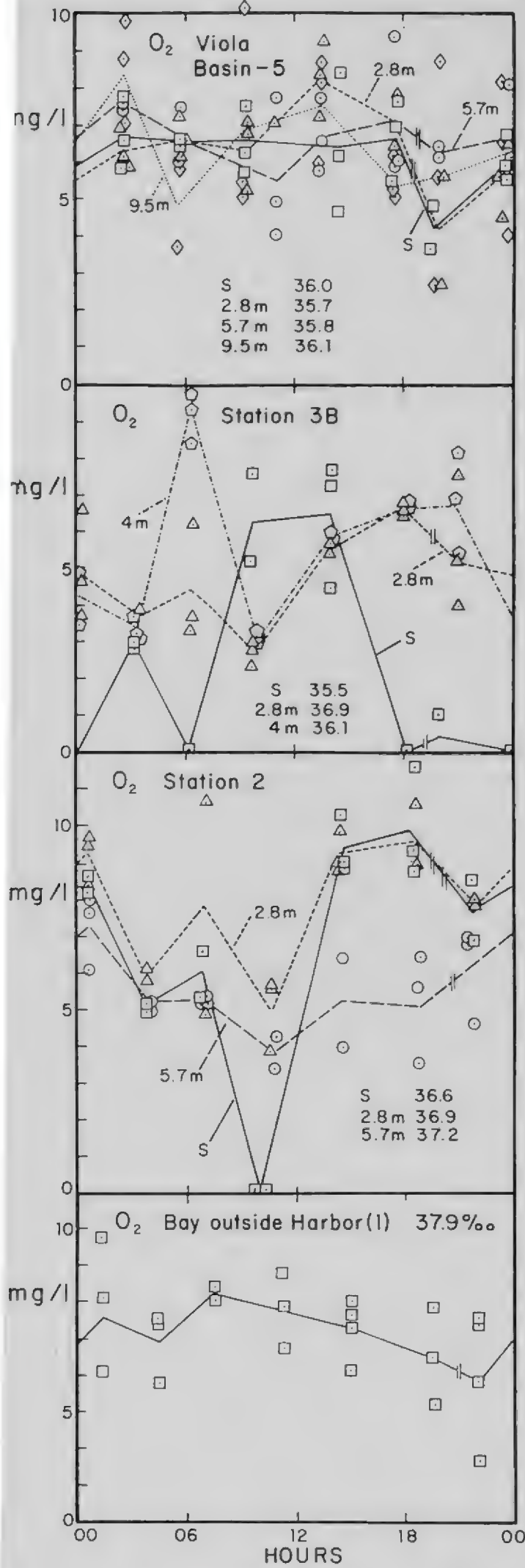
Nueces Bay

Receiving the waste-laden waters of the Corpus Christi Harbor through the cooling tunnels from the south side, Nueces Bay served alternately as a low salinity flushing basin when the Nueces River discharge was large and high salinity trap when the river discharge was small. Much of the bay was only a meter deep or less. It contained some of the exposed oyster reefs that formerly were more extensive in the bay before heavy dredging activity for buried shell converted some reef areas into a plain of soft sediment. Live oysters were still found on the remaining reefs during the fairly low salinity periods, such as 1958. They disappeared during the very high salinity periods (45‰), such as in 1956. Because of the shallow depth, diurnal measurements were very sensitive indicators of metabolism expressed in large amplitudes of pH and oxygen (Fig. 25 and Table 4).

Diurnal curves are compared in Fig. 25 before and after a period of heavy floods from the Nueces River which dropped the salinity of the bay from 31-36‰ to less than 1‰. For autumn conditions of incident solar energy, photosynthesis and respiration were high on October 5-6 and especially so on Nov. 1-2, a couple of weeks after the flood. Although the salinity change was enough to completely displace or kill most of the higher animals and plants, the metabolism of the whole bay system continued with high values. Agreement between stations was fairly good so that the mean could be used with some confidence to represent the overall metabolism of the bay (Table 4). Respiration exceeded gross photosynthesis both in the relatively stagnant high salinity condition in summer and in the low salinity flushing period, suggesting a prominent role of wastes as fuel during the first period and river-borne organic matter during the flushing period. Water was somewhat deeper while under a freshwater hydrostatic head.

It has already been pointed out that the measurements of depth are as important to calculations of bay metabolism as the chemical determinations. The temperature curves indicate the integrating effect of the drifting water masses. Whereas water isolated in

Corpus Christi Ship Harbor July 20-21, 1962



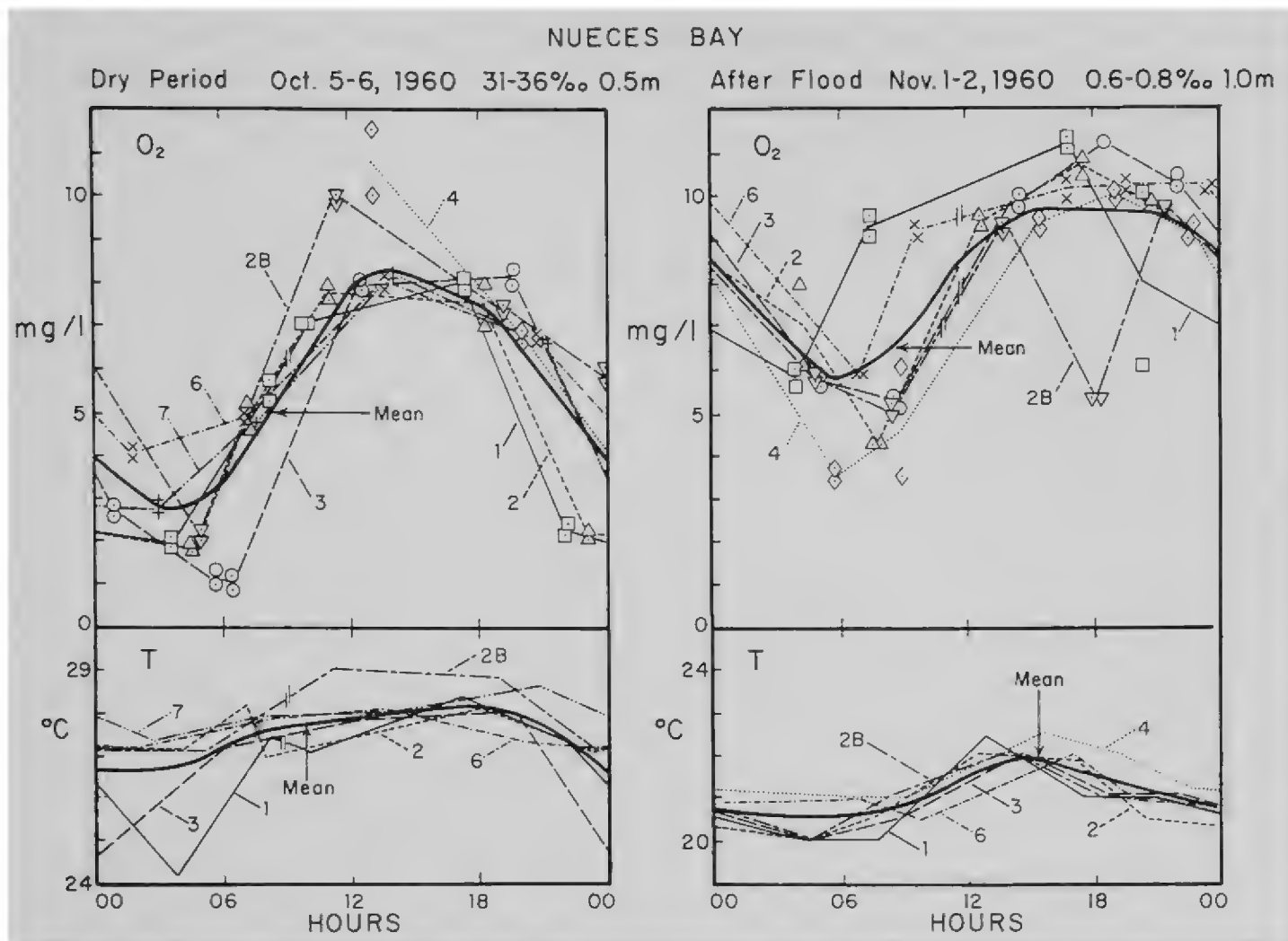


FIG. 25. Diurnal records of oxygen and temperature at multiple stations in Nueces Bay on Oct. 5-6, 1960 and on Nov. 1-2, 1960 after floods lowered the salinity. The heavy line is the mean of the curves.

shallow depth concentrates insolation with a higher amplitude of temperature than in deep water, the curves from different depths in Nueces Bay are of similar amplitude. The water moving from one depth to another is integrating the diurnal effects. Thus, analysis of either multiple or single station data should be made with the general depth of the bay vicinity rather than a particular station depth.

The two sets of diurnal curves in Fig. 26 for August 3-4, 1961, and June 26-27, 1961, presented a different pattern. Although light and salinity conditions were more favorable, diurnal metabolism was small or non-existent. Respiration was greater than photosynthesis, but both were small and efficiency of utilization of the high energies received on both days was low. There can be little doubt that the productivity of Nueces Bay at this time was much diminished by some properties in the water. Similar low metabolism was computed from data for July 30-31, 1959 (Table 4).

In Fig. 27 are shown two diurnal curves in the lower parts of the Nueces River. There was some diurnal change in the oxygen and pH curves, indicating some photosynthetic plankton metabolism. Respiration from organic matter was not excessive since oxygen levels were not much different from saturation. No metabolic computation was attempted since the upstream and downstream stations were not identical and stream data were incomplete. As a diluting medium the river water at that time was not showing properties likely to have strongly modified the Nueces Bay metabolic patterns.

FIG. 24. Diurnal record of oxygen, pH, and light at 4 stations in the Corpus Christi Ship Harbor, July 20-21, 1962.

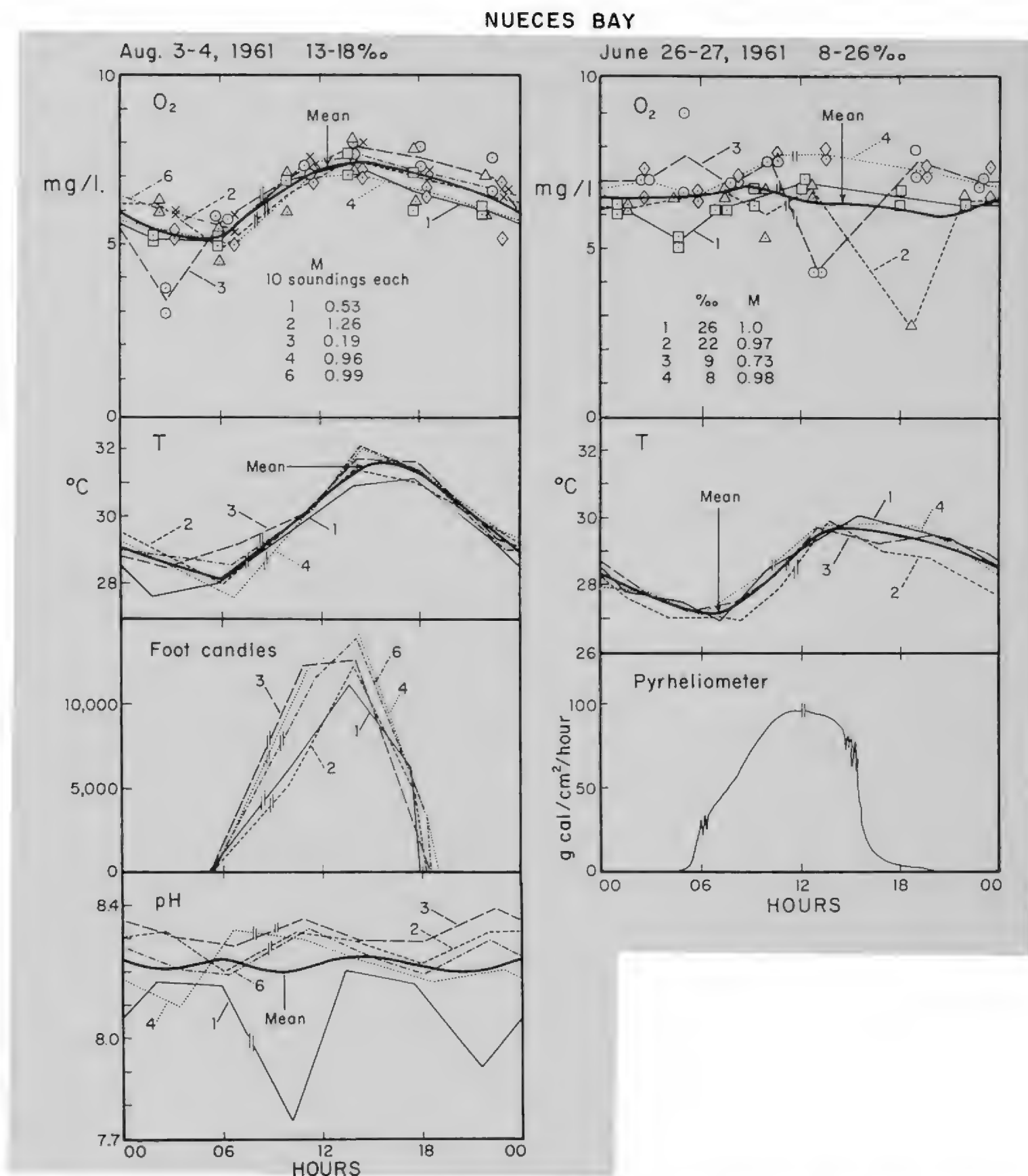


FIG. 26. Diurnal records of variables at several stations in Nueces Bay Aug. 3-4, 1961 and June 26-27, 1961.

When tested October 1-6, 1960, with the exception of station 2B near effluents, the Ohle anomaly in Nueces Bay was small and oxidizing (Table 2). Total phosphorus values obtained in Nueces Bay were moderately high (Table 3 and Fig. 7). On July 5, 1961 in the Nueces River at the Route 77 Bridge, 529 and 166 ppb were found.

Corpus Christi Bay

The waste waters entering the Corpus Christi Harbor and Nueces Bay are exchanged

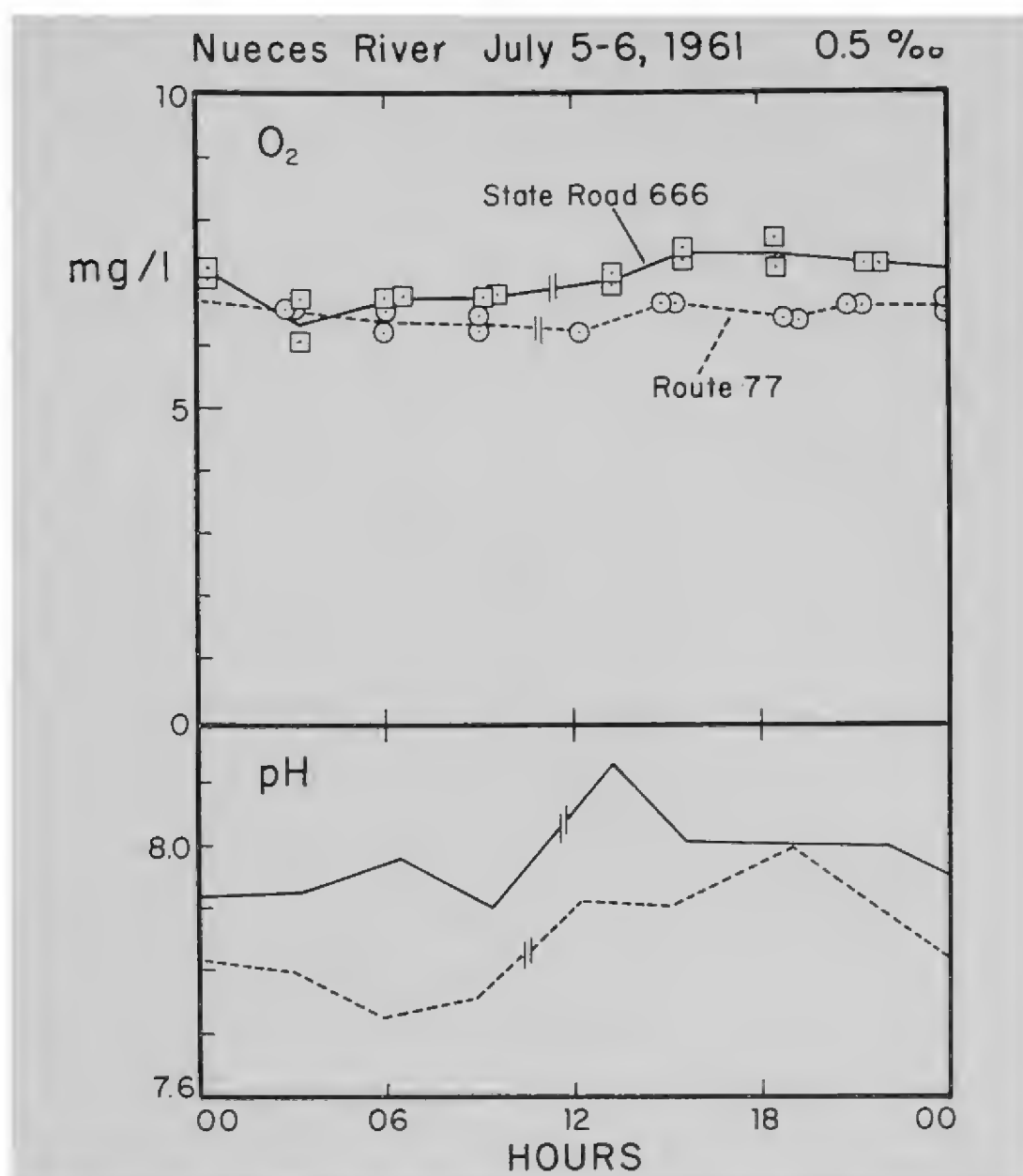


FIG. 27. Diurnal record of oxygen and pH at two stations on the Nueces River July 5-6, 1961.

with the western end of Corpus Christi Bay, a well mixed body, 3 to 4 m deep (Fig. 1). Wastes were also entering from aluminum and oil drilling industries on the north side. On the south side treated wastes from municipal effluents were entering indirectly through Oso Bay and from the Naval Air Station.

In a hydrographic survey, Hood (1953) indicated the land-locked properties of Corpus Christi Bay and the small tidal exchange with the Gulf. At that time he warned of the infrequent flushing and conditions favoring accumulation of wastes.

Diurnal curves of oxygen, pH and related variables are given in Fig. 28-31 for 11 stations (see Fig. 1). Stations 1-5 were taken from a launch making a circle every 3 to 5 hours. Station 6 was in the La Quinta Ship Channel 10 m deep leading to the Reynolds Aluminum Plant. Stations 7-11 were at the end of long fishing piers and sampled from shore. Where agreement existed among stations the mean metabolism of the bay was calculated (Table 4).

In the data for Oct. 13-14, 1960, boat stations may be compared with pier stations; temperatures, salinities, range of oxygen values, and dispersion of oxygen data are similar. However, an examination of single diurnal curves indicates greater irregularity and deviation from the regular diurnal curve in the pier stations as might be expected from water moving along the shores over some plant beds, receiving wastes, and less mixed. The La Quinta Channel (station 6) was somewhat stratified with little

Corpus Christi Bay Oct. 13-14, 1960

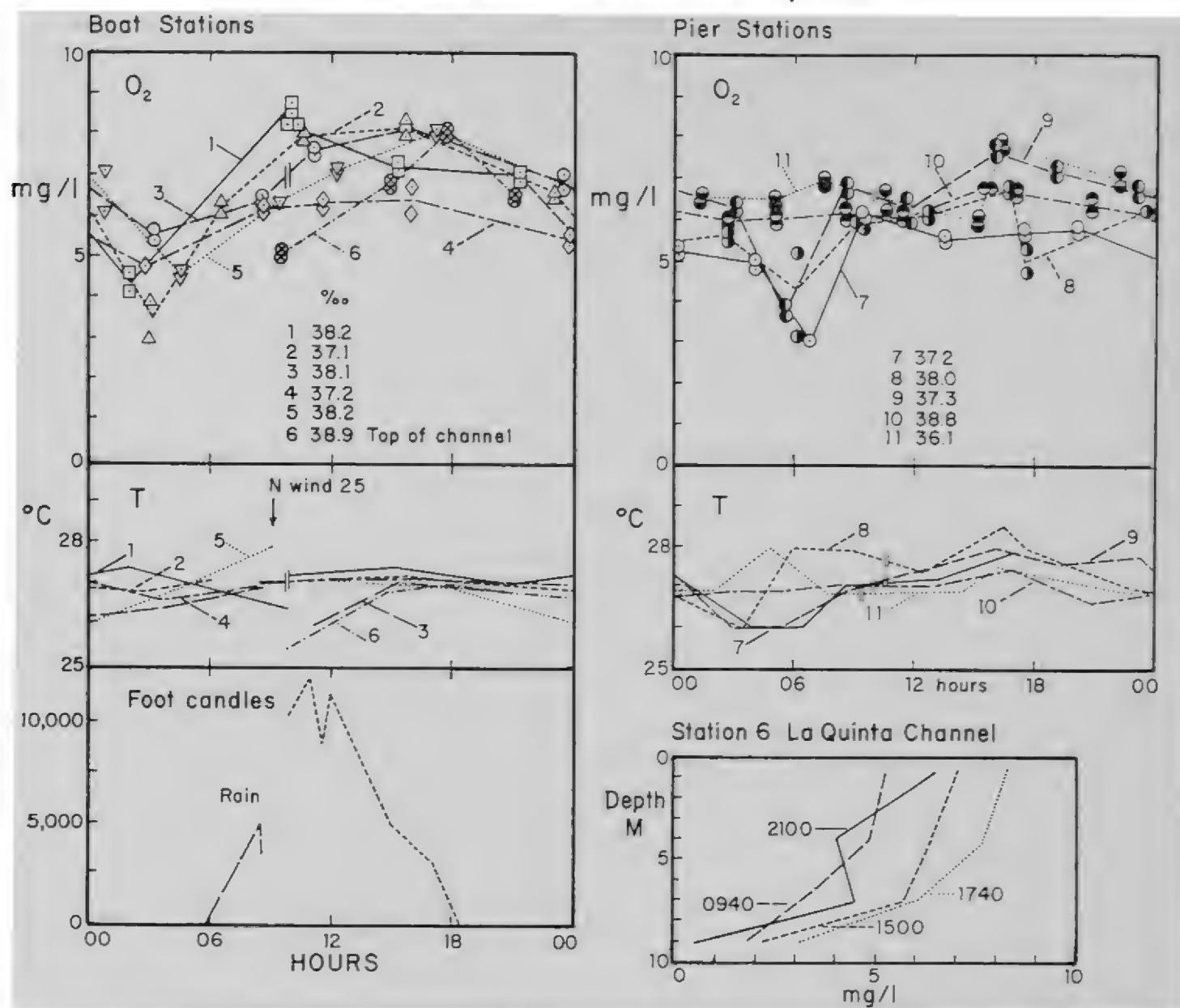


FIG. 28. Diurnal record of variables at stations in Corpus Christi Bay, Oct. 13-14, 1960.

oxygen at the bottom, but the diurnal rise and fall in oxygen was observed at all depths indicating a high productivity per surface area.

On Dec. 28-29 (Fig. 29), with relatively little incoming insolation indicated, oxygen values were very uniform and the diurnal swing with photosynthesis was hardly detectable. The uniformity of the salinities indicates the well mixed condition.

The species diversity counts in zooplankton expressed in species per thousand individuals counted were graphed in Fig. 32. This plot runs from the much polluted waters of Viola Basin, through Corpus Christi Bay to the inlet at Port Aransas, and 25 miles into the open Gulf. Species diversity ranged between 2 and 25 species per thousand.

The two days in May and June (Fig. 30) represent a contrast to the winter condition in Fig. 29. Diurnal curves of photosynthesis were clearly recognizable and agreement between stations was good. The mean curves were used to calculate a single rate of change curve for the whole bay on the two dates. In both, respiration was exceeding photosynthesis. Although incoming radiation was similarly large in both instances, photosynthesis and respiration were almost twice as great in the May data from boat stations. In these data the agreement among oxygen samples over the large bay was good and quite in contrast to the wide ranging patterns in Galveston Bay (Figs. 19 and 20).

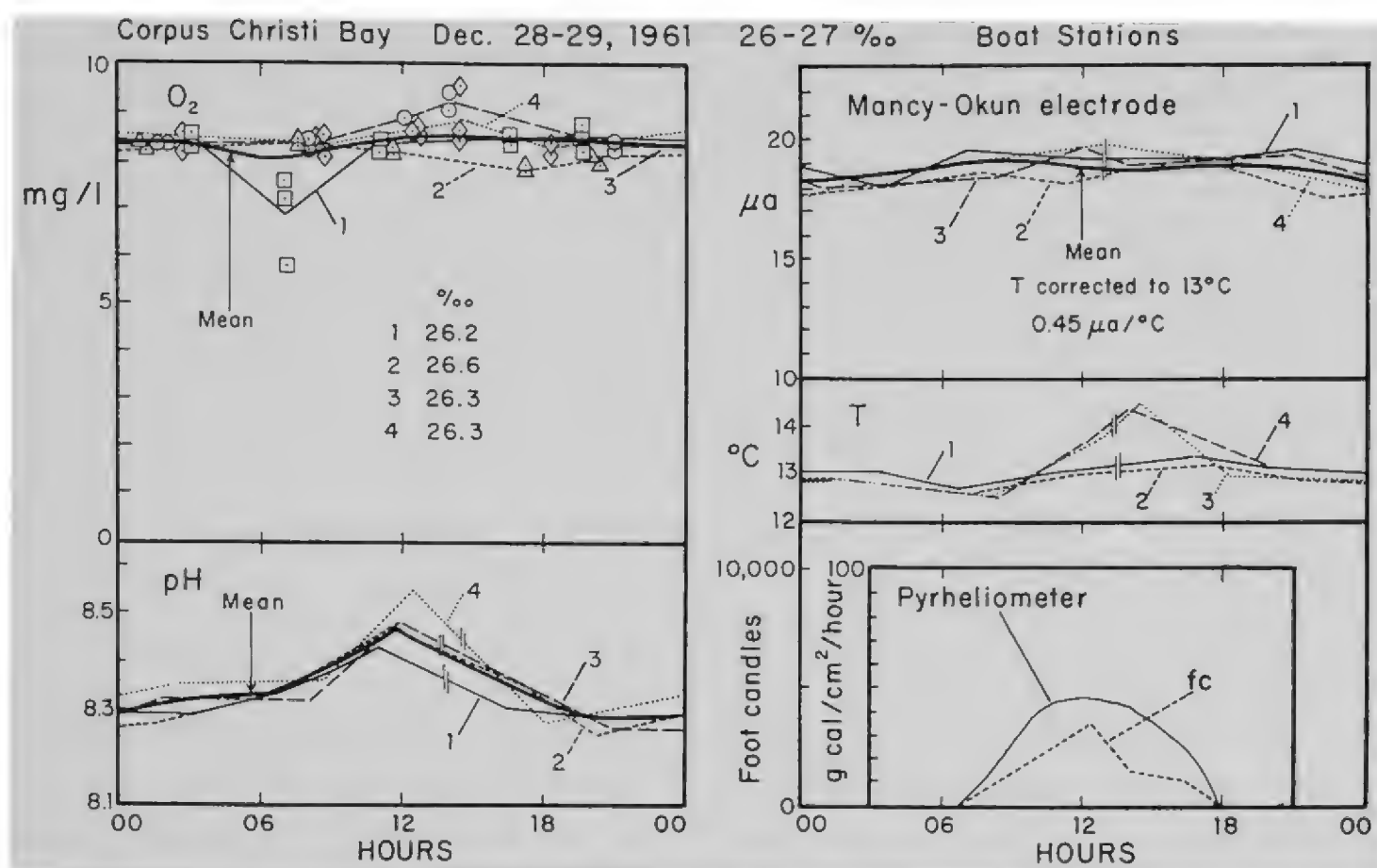


FIG. 29. Diurnal record of variables in Corpus Christi Bay, Dec. 28-29, 1961. The heavy line is the mean of the curves.

On August 9-10, 1961, at four shore stations, a pattern of irregular variation with little consistent diurnal variation was found both in oxygen and pH. Photosynthetic metabolism was small and hardly demonstrable. Phosphorus in Oso Bay, which receives treated municipal wastes, in ppb for July 11, 1961, were 394, 2, 455, 480, 64, 66, 173, and 168; and for March 6, 1961, 71 ppb.

During 1961 the total phosphorus in the bay varied considerably (Table 3 and Fig. 1). For example, values were relatively lower on April 22, whereas May 22 values were much higher. The group of boat stations (stations 1-5 in Fig. 1) possessed lower phosphorus content more like that of Gulf water from Port Aransas as compared with samples from the peripheral pier stations (stations 7-11). Phosphorus levels were very high for both May 22 and August 8 whereas the metabolic patterns for these days (Figs. 30 and 31) were very different. The August graphs indicated little metabolism in spite of the high nutrient level.

Levels in March were much lower following the winter season. In winter the frequent passage of northers drops the outside Gulf tidal level as much as two feet for several days. The low tide permits the Corpus Bay system to flush out an appreciable part of its water and then to replace it with new Gulf water when the winds swing to the south and east on the reverse flow of passing cyclonic systems. Values in the mouth of Corpus Christi Harbor during 1961 were generally similar to those just outside in Corpus Christi Bay. This is consistent with the usual flow inward into the harbor mouth, driven by the large cooling flows of the industries pumping northward into Nueces Bay.

Data from Less Disturbed Bays

In *San Antonio Bay*, a low salinity bay fed by the Guadalupe River, March 3, 1962,

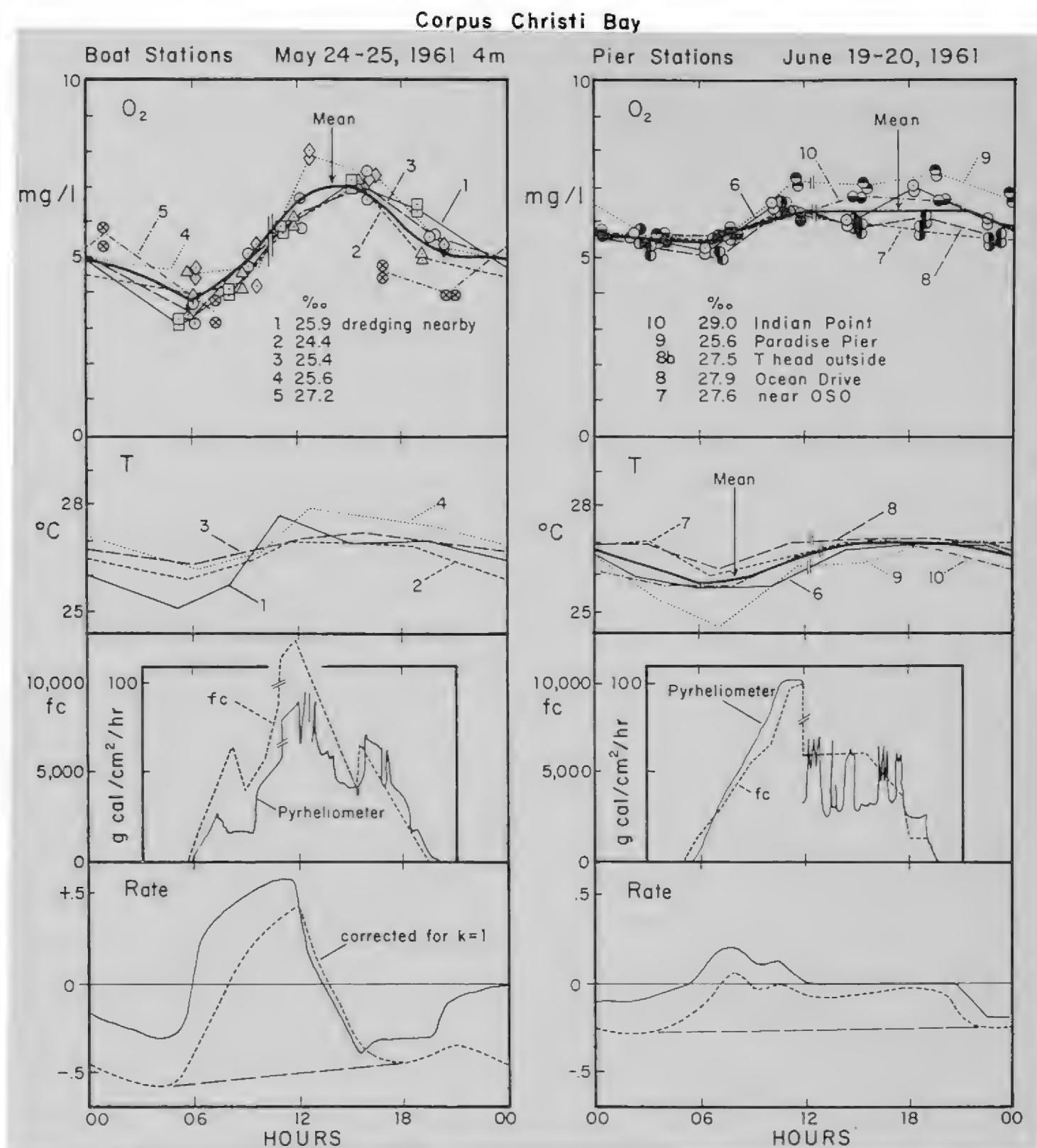


FIG. 30. Diurnal record of variables in Corpus Christi Bay, May 24-25, 1961 and June 19-20, 1961. The heavy line is the mean of the curves.

diversities were 1 species per thousand. On June 12, 1962, data indicated 8, 6, 5, 6, and 7 species per thousand. Total phosphorus in the Guadalupe River on May 28, 1961, was 228 ppb.

In the *Laguna Madre* of Texas on May 8, 1962, diversity measurements were made from Port Aransas to Brownsville as follows: Values in Corpus Christi Bay were 19, 15, and 15 per thousand; in the hypersaline region in upper Laguna Madre, values were 12, 9, 11, 9, 11, and 10; in the region of the land-cut south of Baffin Bay, values found were 9, 12, and 10; in the lower Laguna Madre, values were 13, 13, 12, 7, 10, and 10. These data are similar to those in the Brownsville Shrimp-boat channel (Fig. 4). In August 1960 the upper Laguna Madre had total phosphorus values of 43, 47, 36, 37, and 33 ppb, slightly lower than the 1957 data (40 to 130 ppb).

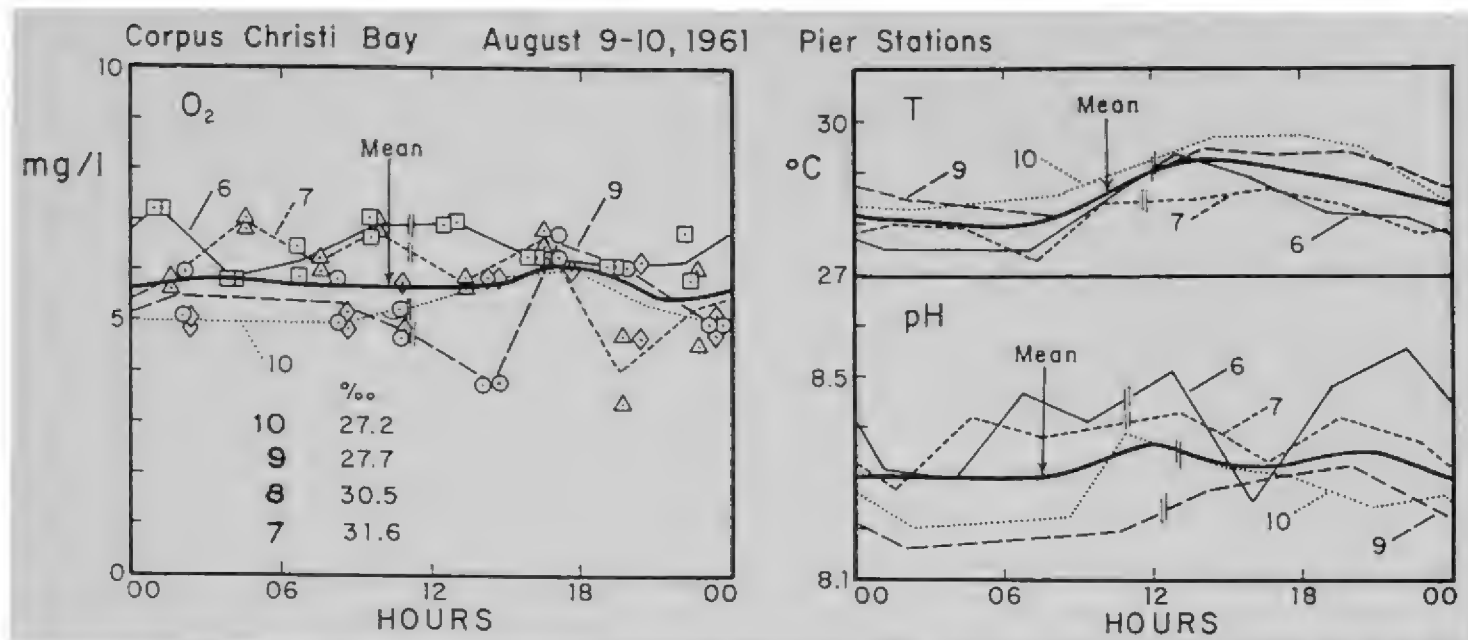


FIG. 31. Diurnal record of variables in Corpus Christi Bay from pier stations Aug. 9-10, 1961. The heavy line is the mean of the curves.

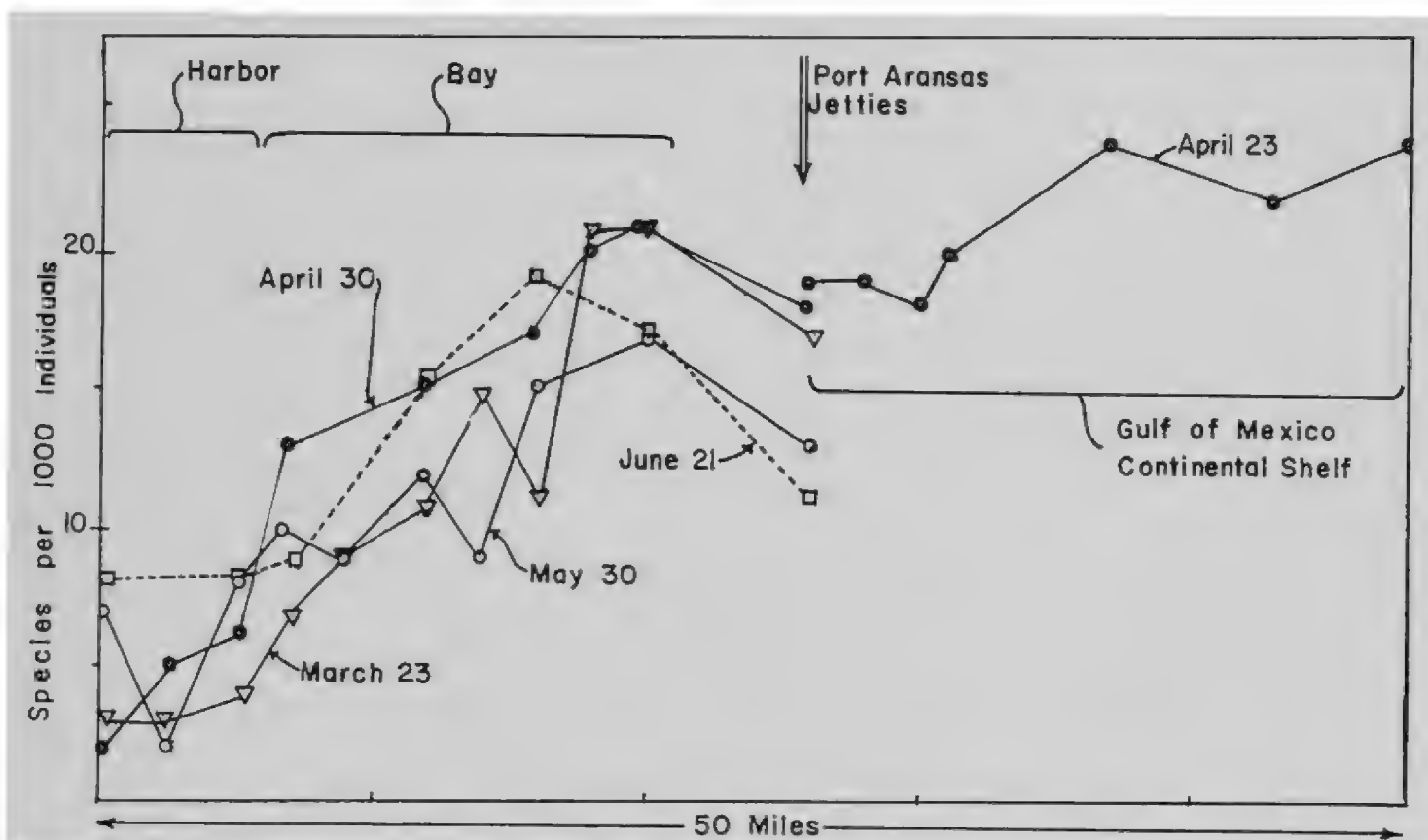


FIG. 32. Species diversities in zooplankton (species per thousand individuals) from the western end of Corpus Christi Harbor to a station 25 miles out on the shelf of the Gulf of Mexico off Port Aransas. (See Map in Figure 1.)

For *Aransas Bay*, values for species diversity were obtained from the water of the Gulf at Port Aransas jetties to the low salinity waters of Copano Bay. Diversities in Aransas Bay (see top of Fig. 1) ranged from 4 to 23 species per thousand. During the winter, as on Nov. 27, 1961, Dec. 8, 1961, Dec. 21, 1961, Jan. 29, 1961, and March 8, 1962, diversities at Port Aransas ranging 14-23 species per thousand decreased as one passed north in Aransas Bay to 1, 6, 6, 5, and 8 species per thousand. In contrast, the spring and summer series, April 16, May 25, and June 12, showed little difference between Port Aransas and the northern end; diversities were 10 to 18 species per thousand throughout. During this period salinity ranged from 29 to 33‰ at Port Aransas, as compared to lower values of 24 to 27‰ at the northern end of the series. Total phosphorus values were 76, 75, and 55 ppb, May 28, 1961.

Redfish Bay, the shallow bay opposite Port Aransas (Fig. 1) is covered with benthic communities such as turtle grass and has a more constant salinity. Salinities during the 1962 period were between 25 and 33‰. Species diversities on March 16, 1962, were 11, 13, 11, 10, 9, 19, and 13. On April 13, 1962, values were 14, 15, 8, 10, 10, 4, 10, 14, and 14. On May 23, 1962, the values were 13, 17, 14, 16, 17, 16, 18, and 11 species per thousand; and 16, 11, 13, 12, 10, and 11, on June 7, 1962. In addition to total phosphorus analyses reported for 1962 (Fig. 3), 41 and 37 ppb were found July 31, 1961, and 48 and 26 ppb July 5, 1961.

Sabine Bay (Lake) in east Texas receives the Sabine and Neches Rivers and has a low salinity community. Although there are heavy waste flows in the system, much of it by-passes the main Sabine Bay via the Beaumont-Port Arthur Ship Channel. In a traverse, the length of the bay, species diversities on April 7, 1962, were 15, 9, 7, 12, and 9 species per thousand; and on July 17, 1962, species diversities were 8, 6, 6, 4, 9, and 16 species per thousand. Total phosphorus of 288 and 128 ppb was measured in the Sabine jetties.

Matagorda Bay was studied for species diversity. In the main bay on March 22, 1962, diversities were 10, 9, 10, and 11 species per thousand. On June 22, 1962, values were 9, 17, 19, and 5 species per thousand. Lower values (3, 6, and 4) were found in Lavaca Bay and near Palacios (4 and 4). Wastes were received in these areas. In the south and east portion of Matagorda Bay total phosphorus on August 15, 1961, was 108, 116, 135, 89, 108, 119, and 121 ppb. In Lavaca Bay, May 28, 1961, total phosphorus in ppb was 204, 82, and 286; in Tres Palacios Bay values were 490, 447, and 494 ppb; and in the Colorado River, 216 and 225 ppb.

Copano Bay which receives extensive bleedwaters had 175, 178, 240, 248, 118, and 144 ppb phosphorus on June 12, 1961.

Freeport Jetties showed total phosphorus on the north side to be 133 and 153 ppb on Oct. 14, 1961.

In *Baffin Bay*, on April 27, 1961, total phosphorus was 98 and 254 ppb at the eastern end. In *Alazan Bay* values were 98 ppb on Feb. 9, 1961; 4 and 86 ppb March 1961; and 3, 10, 15, 40, 36, and 49 ppb in August 1960.

Discussion

One result of these studies was the verification of the diurnal curve method of estimating carbon and oxygen metabolism in the whole bays by widespread simultaneous sampling, by averaging curves, by averaging levels, and by considering each bay as a single swirling biogeochemical system. The phosphorus, Ohle anomaly, and diversity measures helped to confirm interpretations based on the diurnal oxygen and pH patterns. The several types of measurements tested showed some anomalies or extremes in magnitude in the bays receiving waste discharges, but the differences were in degree and there were no sharp boundaries between data from systems disturbed and undisturbed by wastes. Most of the extremes found associated with waste conditions have occasionally occurred without the influence of wastes.

TOTAL PHOSPHORUS

The general levels of total phosphorus were somewhat documented in a previous paper as about 40 ppb in the open Gulf increasing to about 150 ppb in the hypersaline

bays (Odum and Wilson, 1962). In this paper the levels of phosphorus in the bays receiving wastes ranged generally higher up to 2000 ppb or more. The sources of wastes from treated municipal wastes, seafood processing wastes, bleedwaters, and some industrial wastes were characterized by higher phosphorus values. Thus, values even higher than the natural values in the hypersaline bays were found in Galveston Bay, Conn Brown Harbor, Corpus Christi Harbor, Corpus Christi Bay and elsewhere.

The higher values in Corpus Christi Bay in 1961 and 1962 when the salinities were high in the bay (35 to 36‰) contrast with some low values in 1957 and 1959 when salinities were lower and less industrial and municipal wastes were incoming. The total phosphorus measurements may be useful as indicators of the retention of relatively high levels of waste, especially when the high levels of phosphorus are accompanied by a decrease in effective metabolism. The accumulations of total phosphorus in the larger Texas Bays can readily serve as major fertilization influence exchanged into the open Gulf abruptly at times of strong cold fronts, low tidal set, or with flood conditions, causing freshwater flushing.

METABOLISM FROM DIURNAL CURVES

The metabolism and diurnal curve patterns in the bays receiving wastes ranged from very slight metabolism to very large values both in comparisons from place to place and also from time to time in the same place. The very large rates of photosynthesis and respiration in some instances in Galveston Bay (40 to 60 g/m² per day) were equal to or greater than the high natural values in turtle grass of the lower Laguna Madre. Low metabolic rates (1–3 g/m² per day) suggest toxicity in some stations in ship harbors, near Texas City, and in some instances in the larger bays. However values were not lower than in some graphs associated with extreme natural conditions such as in the Mexican Laguna Madre.

METABOLIC QUOTIENTS

As already found by Park et al. (1958) in some bays less affected by wastes, the ratio of carbon and oxygen metabolism from diurnal curve methods often deviated from the range of simple metabolic patterns (between 0.7 and 1.0 for glucose, protein, or fats). Thus, the metabolic quotients mainly ranged from 0.4 to 1.9. In bleedwaters strange diurnal ratios (Fig. 9 and Table 4) were traced to the out-of-phase pattern of photosynthesis and respiration in the cycle from daytime oxidative conditions to nighttime reducing conditions with some carryover of residual products the following day.

EFFICIENCIES OF GROSS PHOTOSYNTHESIS

With multiple stations replicating diurnal data from the same bay and with accurate pyrhelimetric measurements of available energy, it has been possible to accurately measure the range of photosynthetic efficiency found in Texas Bays, mainly 2.0% to 4.0% (Table 4) of visible wavelengths received. These values are a little less than those inferred with less accurate solar data in previous papers (Odum and Hoskin, 1958; Odum and Wilson, 1962).

ZOOPLANKTON DIVERSITY

As a measure of complexity of the plankton system, the diversities were highest

(10 to 25 species per thousand individuals) in the more stable environments, the open Gulf and Redfish Bay; and lowest (1 to 10) in disturbed environments of the inner harbors receiving wastes, such as Conn Brown and Corpus Christi Harbors, San Antonio Bay, and the more briny environments. Similar decreases in species numbers were found by Reish (1960) in marine waters of Los Angeles.

Something of an unsolved question concerns the diversity in areas of contact between large marine systems. For example, data in Fig. 32 suggest a decrease in diversity in the zone of mixing at Port Aransas between the bays and open Gulf, whereas one line of reasoning might predict greater diversity in an ecotone. By another theory, severity of fluctuations might favor less structural diversity. Whereas low species diversities are classically related to the upper oligohaline zones of river estuaries as attributed to the lack of adaptations of species to low salinities, other theories attribute low diversities to the fluctuations in conditions rather than to the low salinity. In support of this view are the very diversified faunas in Florida's spring-fed rivers which have oligohaline waters without the sharp shocks of salinity and turbidity changes of river mouths (Odum, 1953a).

In the instance of the decline in species diversity from the open Gulf to the low values of Corpus Christi Harbor (Fig. 32) salinity during the 1961-62 period covered did not fall below 30‰ in the entire system from the harbor to the Gulf. Here the salinity factor was certainly not causing the decline in diversity of zooplankton. More attractive is the hypothesis that simple ecosystems result from disturbance phenomena, in this case from wastes in the western end of the Corpus Christi Bay system. Hohn (1959) using diatoms on slides demonstrated low diversities in the Houston Ship Channel.

OHLE ANOMALY

The Ohle anomaly was found to be useful as a measure of waste influence, since large and variable anomalies were found in the inner harbors and places of known heavy waste influence. Oxidizing anomalies were as common as reducing anomalies and the presence of substances affecting the anomaly was accompanied by greater variation in replications than in less affected waters. Thus anomalous Winklers confirmed by the Ohle analysis indicated inaccurate oxygen data and more spot to spot variation than usual. Some evidence for a diurnal variation in Ohle anomaly was observed in bays with a large daily oxygen range (Table 2). Generally the bays not strongly affected by wastes had Ohle anomalies less than 0.2 mg/liter.

TYPES OF WASTE-DOMINATED ECOSYSTEMS

In a previous paper (Odum, 1960b) several types of waste receiving systems were described according to their diurnal curves. These new data may be considered in relation to that classification also.

1. *Large excess of photosynthesis over respiration.* This type was rare in these bays. Water receiving inorganic nutrients were also receiving heavy loads of organic matter. On one day (July 16-17, 1960) Nueces Bay had photosynthesis twice respiration.

2. *Large excess of respiration over photosynthesis.* By far most of the graphs were of this type. The harbors, large bays, and the bleedwater lagoon had undersaturated waters much of the time. Examples were Figs. 14 and 15, stations 13 through 15 in

Fig. 19, and Fig. 30. Because an excess of respiration over photosynthesis also means that nutrients are being regenerated faster than used, such systems often had very high rates of photosynthesis also.

3. *Similar magnitudes of photosynthesis and respiration but both processes augmented.* This type was recognized by a very large amplitude of the diurnal curves both above and below oxygen saturation. Examples are Figs. 6, 18, and 25. Productivities were greater than found in comparable bays not receiving wastes. Important unsolved questions are: What course would metabolism take if the waste inflows were stopped and no general flushout occurred? Would metabolism remain high or would it return to levels of the unaffected bays? Would the ecosystem be able to recycle nutrients fast enough to maintain concentrations presently maintained in part by waste inflows?

4. *Diminished metabolism and toxicity.* Instances where metabolism was much diminished and even eliminated were observed in many instances. This type was recognizable by the absence of a diurnal curve in pH or oxygen and by near saturation conditions throughout the day. Examples are station 3 in Fig. 5, station 3 in Fig. 16, station 12 in Fig. 19, and the June 26–27 curve in Fig. 26. The occurrence of such curves during the summer period when the bays are normally highly productive (Odum and Wilson, 1962) is a sign that the man-made disturbances to the Texas Bays are beginning to reduce the productivity in some places and at some times.

5. *Patchy water.* Data in this paper make it necessary to define another pollution type recognized by extreme variation in oxidized and reduced properties over short distances. Diurnal curves for such conditions have large ranges among replicate samples and from time to time both in oxygen and pH. Ohle anomalies for these waters are large, both oxidizing and reducing. Because of the statistical problems, it is impossible to verify a general overall metabolism for the bay. The separate patches of oxidized and reduced water may or may not have significant metabolism. Examples of such data are shown in Figs. 20, 21, 24, and 31. A question which is raised by these data needs to be answered in laboratory studies: Does the alternation of conditions found in such patchy water provide greater stress to fishes and benthic communities than might be inferred from toxicity tests in non-fluctuating conditions?

6. *Stratified channels.* Where narrow ship channels 10 to 12 m deep are cut through shallow bays, temporary stratifications of properties were frequent with and without higher salinities on the bottom. Such systems developed reduced bottom conditions something like those of a classical hypolimnion in several days because of the high rates of respiratory metabolism. The large ratio of volume of the ships to the cross sections of these channels, allowed mechanical stirring by ships to be a major factor. Examples of diurnal patterns in ship channels under stratified conditions are Figs. 6, 22, and 23. Except for a few hours at a time, these same channels were not stratified under other wind, temperature, and salinity conditions, such as in Figs. 21 and 24.

7. *Diurnal deficit system.* Illustrated in this paper by the bleedwater-bluegreen system and with numerous interesting examples by Copeland (1963) and Copeland and Dorris (1962) for waste ponds in Oklahoma, oxygen in very shallow waters with a high metabolic rate, reaches almost zero at night with respiration unable to exceed the inward diffusion rate for oxygen. Anaerobic deficits developed so that in the early morning, oxygen was used as fast as it was produced by photosynthesis until the accumulated deficit of reduced substances was oxidized. Such systems when measured by regular

oxygen and carbon methods tend to have a high ratio of CO_2 to oxygen in metabolic quotients. The high respiratory and photosynthetic quotients often noted in other bays may be due to this property in the bottom parts of bays even when the bay is not so shallow as to develop the accentuated deficits of the bleedwater lagoon.

MARINE RESOURCE IMPLICATIONS

There are many implications from the data concerning the future use of the marine resources of Texas. The phosphorus data document the influence that wastes from one place are having on users in other parts of the bays. Waste levels are already concentrated enough to merit public efforts to separate the waters receiving wastes from general release to the large bays that must also serve for nurseries, recreation, and commercial fishing.

Specifically, for example, the discharge of the Corpus Christi Ship Channel waters north into Nueces Bay makes it certain that the bathing waters of the North Beach will remain polluted. The levels of wastes coming into Galveston Bay from the Houston Ship Channel, the Clear Lake area, and from Texas City and elsewhere are already producing conditions toxic to biotic resources at times while providing shocks of fertilizing influences at other times. The time for a zoning of the bay waters (Odum, 1960c) may be at hand.

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Directions for the Determination of Changes in Carbon Dioxide Concentration From Changes in pH¹

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Abstract

This is a methods paper describing a tonometer apparatus and procedures for the determination of changes in total carbon dioxide concentration in waters from measurements of pH. Where pH changes in water result from the metabolic addition or subtraction of carbon dioxide, continuous records of metabolism may be obtained from pH recordings. The calculations are facilitated by tables and a computer program. A sample calculation is included.

Introduction

In most natural waters, the pH of the water is a function of the dissolved carbon dioxide, and as the carbon dioxide content of the water varies so will the pH of the water vary. This relationship between pH and carbon dioxide has been used in many quantitative and qualitative studies of metabolic carbon dioxide changes in both field and laboratory situations. (Osterhout and Hass, 1919; Hass, 1919; Atkins, 1922, 1923; Wells, 1922; Brujewicz, 1930; Verduin, 1951, 1956a, b, 1957, 1960; Jackson and McFadden, 1954; McQuate, 1956; Odum, 1957a, 1957b; Revelle and Emery, 1957; Park *et al.*, 1958; Jackson and Dence, 1958; Richman, 1958; Hepher, 1959; Wright, 1960; Larimer, 1961; Megard, 1961; Beyers, 1962, 1963a, b; Delco and Beyers, 1963). However, as pointed out by Beyers and Odum (1959, 1960) and Lyman (1961), some of these efforts have not always been free of error. The source of difficulty lies in the nonlinearity of the relationship between carbon dioxide concentration and pH. Change in pH can be translated into change in carbon dioxide in one of two ways: (1) theoretically from computations involving alkalinity and dissociation constants; or (2) empirically by titration or gas analysis. The theoretical methods assume that natural waters are simple solutions containing carbon dioxide equilibria alone, and that they follow simple chemical laws. However the many different dissociation constants in the literature (Black, 1961) indicate the variable nature of the components and equilibria. Verduin (1956a) empirically determined the relationship between pH and carbon dioxide concentration by titration with strong acids and bases, but Beyers and Odum (1959, 1960) and Lyman (1961) indicated that over some pH ranges strong acids or bases could not be used to simulate carbon dioxide. In these previously published notes, carbon dioxide saturated distilled water was described as a titrant for obtaining pH-carbon dioxide

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graphs. In effect, the procedure was a titration with gaseous carbon dioxide using distilled water as a carrier. A known amount of gas (in a known amount of distilled water) was added to the experimental water and the change in pH was measured. From these data a graph was constructed correlating change in pH with change in carbon dioxide concentration.

The curves were then used to estimate metabolic rates of aquatic organisms and ecosystems from pH changes (Larimer, 1961; Beyers, 1962; Delco and Beyers, 1963; Beyers, 1963a). The method has now been used to compute approximately 300 diurnal carbon dioxide rate of change curves at the Institute of Marine Science and a similar number for Mr. John Butler and Dr. Troy Dorris at Oklahoma State University. The method has also been used to measure the respiration of chironomid larvae at Oklahoma State University and decapod crustacea and small minnows at the University of Texas. This paper provides an account of the apparatus, procedure, and a sample calculation on sea water. Dr. K. G. Wood of Thiel College provided a comparison graph done by the Van Slyke method (Wood, 1963).

In the following description, directions are given for (1) preparing the carbon dioxide saturated water with a tonometer burette, (2) titrating the sample water and (3) computing the total carbon dioxide changes. Tables of constants to aid the calculations and a computer program to calculate carbon-dioxide rate of change curves are also included.

Procedure

(1) PREPARATION OF CARBON DIOXIDE SATURATED DISTILLED WATER

Pure carbon dioxide at a flow rate of about 555 cc/min is passed through a copper coil (264 cm long, 0.75 cm inside diameter) to bring the gas to room temperature. The gas goes next to two Fisher-Milligan gas washers (274 cc volume) in series. These gas washers saturate the carbon dioxide with water vapor. The gas next encounters a "Y," one leg of which is closed with a clamp. The other leg leads through a long narrow tube into the barrel of the tonometer burette. This burette is pictured in its cradle in Fig. 1. The specifications for the burette and cradle are given in Table 1. Approximately 60 cc of distilled water is injected into the bulb B with a hypodermic syringe. Care is taken to keep water out of the barrel. The tube carrying the water-saturated carbon dioxide is inserted into the burette through the opening O and pushed down into the

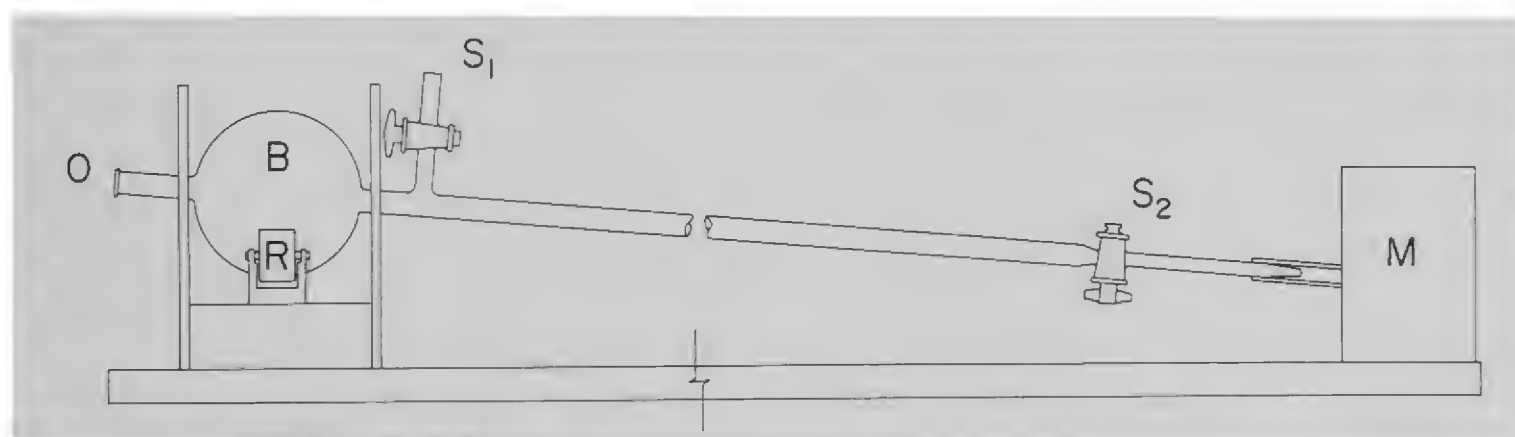


FIG. 1. Tonometer burette in its cradle. Tonometer is rotated in this position to prepare carbon dioxide saturated distilled water. Burette is turned upright for titration. Opening O admits the gassing tube. B is the bulb which turns on the rollers R. Stopcock S_1 allows the introduction of carbon dioxide into the tonometer when it is in the upright position. Stopcock S_2 controls the flow of titrant during the titration. The motor M rotates the tonometer at 30 rpm during the equilibration period.

TABLE 1

Specifications for tonometer burette and cradle. Burette is fabricated from a standard 50 ml burette graduated in 0.1 ml increments.

Outside diameter of bulb	10.14 cm
Outside diameter of barrel	1.36 cm
Outside diameter of delivery tube below stopcock S ₂	0.79 cm
Total length of barrel	77.19 cm
Total length of delivery tube	13.00 cm
Distance from base of bulb to first graduation on burette	17.49 cm
Distance from bottom of stopcock S ₁ to first graduation	12.86 cm
Total length of tonometer	104.00 cm
Slope of burette barrel in cradle	6°
Motor	Model SG15—30 RPM Merkle-Korff Gear Co. 213 Morgan St., Chicago, Ill.

barrel until the end comes to rest near stopcock S₂ which is closed. The stopcock S₁ is also closed at this time. The motor M is started and the tonometer rotated at 30 revolutions per minute for twenty minutes. The bulb turns on the rollers R. During the rotation the carbon dioxide fills the barrel and bulb of the burette and saturates the water in the bulb. The water is spread out in a thin film on the sides of the bulb, and the film is constantly renewed as the bulb rotates. This action hastens the equilibrium of the CO₂ with the distilled water. During the rotation a standard mercurial barometer is read and the temperature of the barometer taken.

After twenty minutes have elapsed, the motor is turned off. The small gassing tube is withdrawn from the burette and clamped. The stopcock S₁ is opened and the carbon dioxide is again admitted into the tonometer via the larger diameter tube attached to the other leg of the Y. The tonometer is inverted and water is allowed to run down into the barrel. This inversion is done gently avoiding any bubble formation. The tonometer is then placed in a burette clamp and about 10 ml of titrant is drawn into a small beaker. This procedure provides a sample of titrant for temperature determination and also provides that saturated carbon dioxide water will fill the delivery tube below stopcock S₂. The burette and titrant are now ready for the titration.

(2) TITRATING THE CARBON DIOXIDE WATER VS pH

The water to be used is bubbled with carbon dioxide-free air or nitrogen until the pH of the sample is above the range of metabolic interest. A sample of the high pH water 100, 200, or 300 ml in volume is pipetted into a beaker for the titration. The titrant is introduced from the burette tip in 0.1 or 0.2 ml increments under the surface of the sample water. After each increment of titrant is added the pH of the sample is measured. Stable pH's are achieved in 10 to 15 seconds after the introduction of the carbon dioxide water provided the sample is gently stirred with a stirring rod or magnetic stirrer in such a way as not to break the surface of the liquid. A table of data results like the first two columns in Table 2. As Lyman (1961) has pointed out, in performing titrations to obtain pH-carbon dioxide correlation curves, the volume of distilled water added must not be so large as to change significantly the alkalinity of the sample water. An average titration of a 300 ml sample requires about 15 ml of carbon dioxide-water, a volume which alters the alkalinity by a maximum of only 5% at the end of the titration. Since the quantity of water in the sample beaker changes after each

TABLE 2

Data from a typical carbon dioxide-water titration of sea water. This water was taken from the vicinity of Woods Hole, Mass. The table shows the pH of the sample after the addition of each increment of titrant (Column 1); the mls of titrant added (Column 2); relative concentration of carbon dioxide in the sample after each addition of titrant using the relationship in equation (11) (Column 3); and the actual concentration of carbon dioxide in the sample after each addition using the relationship in equation (10) and Dr. K. G. Wood's determination of X (Column 4). The quantity X represents the carbon dioxide concentration at the start of the titration. A 300 ml sample was used.

pH of sea water	ml of titrant added	Relative concentration of CO ₂ in the sea water (mM/l)	Actual concentration of CO ₂ in the sea water (mM/l)
8.93	0.0	X + 0.000	1.424
8.91	0.2	X + 0.022	1.445
8.89	0.4	X + 0.045	1.467
8.87	0.6	X + 0.067	1.488
8.82	0.8	X + 0.089	1.509
8.80	1.0	X + 0.112	1.531
8.78	1.2	X + 0.133	1.552
8.75	1.4	X + 0.156	1.573
8.72	1.6	X + 0.178	1.594
8.70	1.8	X + 0.200	1.615
8.68	2.0	X + 0.222	1.636
8.66	2.2	X + 0.244	1.657
8.62	2.4	X + 0.266	1.678
8.59	2.6	X + 0.288	1.699
8.57	2.8	X + 0.309	1.720
8.54	3.0	X + 0.331	1.741
8.51	3.2	X + 0.353	1.762
8.49	3.4	X + 0.375	1.783
8.45	3.6	X + 0.397	1.804
8.42	3.8	X + 0.419	1.825
8.40	4.0	X + 0.440	1.846
8.36	4.2	X + 0.462	1.867
8.33	4.4	X + 0.484	1.887
8.30	4.6	X + 0.506	1.908
8.26	4.8	X + 0.527	1.929
8.22	5.0	X + 0.549	1.949
8.18	5.2	X + 0.570	1.970
8.15	5.4	X + 0.592	1.991
8.11	5.6	X + 0.613	2.011
8.07	5.8	X + 0.635	2.032
8.03	6.0	X + 0.656	2.052
7.99	6.2	X + 0.678	2.073
7.92	6.4	X + 0.699	2.094
7.85	6.6	X + 0.721	2.114
7.80	6.8	X + 0.742	2.134
7.74	7.0	X + 0.763	2.155
7.66	7.2	X + 0.784	2.175
7.60	7.4	X + 0.806	2.196
7.51	7.6	X + 0.827	2.216
7.44	7.8	X + 0.848	2.236
7.39	8.0	X + 0.869	2.257
7.32	8.2	X + 0.891	2.277
7.27	8.4	X + 0.912	2.297
7.21	8.6	X + 0.933	2.317
7.16	8.8	X + 0.954	2.337
7.10	9.0	X + 0.975	2.358
7.05	9.2	X + 0.996	2.378
7.01	9.4	X + 1.017	2.398
6.97	9.6	X + 1.038	2.418
6.93	9.8	X + 1.059	2.438
6.90	10.0	X + 1.080	2.458
6.87	10.2	X + 1.101	2.478
6.83	10.4	X + 1.121	2.498
6.80	10.6	X + 1.142	2.518

TABLE 2—Continued

pH of sea water	ml of titrant added	Relative concentration of CO ₂ in the sea water (mM/l)	Actual concentration of CO ₂ in the sea water (mM/l)
6.78	10.8	X + 1.163	2.538
6.75	11.0	X + 1.184	2.558
6.72	11.2	X + 1.205	2.578
6.70	11.4	X + 1.225	2.597
6.67	11.8	X + 1.267	2.637
6.63	12.2	X + 1.308	2.676
6.60	12.6	X + 1.348	2.716
6.58	13.0	X + 1.390	2.755
6.50	14.0	X + 1.492	2.853
6.42	15.0	X + 1.594	2.950
6.37	16.0	X + 1.695	3.047
6.31	17.0	X + 1.795	3.143
6.28	18.0	X + 1.895	3.238
6.23	19.0	X + 1.994	3.333
6.20	20.0	X + 2.092	3.427
6.12	22.0	X + 2.287	3.614

introduction of titrant, the constantly changing volume must be corrected to a one liter basis by using the "F" factors before plotting the graph.

After the titration, the sample may be used for other purposes. The fact that the sample is altered only by the addition of a few ml of distilled water is of great advantage in applications of this method to work where water is at a premium.

(3) COMPUTING TOTAL CARBON DIOXIDE CHANGES

The carbon dioxide concentration of the titrant after equilibration in the tonometer is a function of the barometric pressure and the temperature according to the laws for the solubility of gases. From the basic data of Bohr (1899) a table of M values for carbon dioxide concentration in distilled water was calculated on a CDC 1604 computer using the relation:

$$M = \frac{(B - b_{t_b} - w_{t_t})(a_{t_t})}{(B_s)(\text{ml/mM})} \quad (1)$$

where

M is the millimoles CO₂ per ml of titrant.

B is the observed barometric pressure in mm Hg.

b_{t_b} is the brass scale temperature correction in mm Hg at the temperature of the barometer.

w_{t_t} is the water vapor pressure in mm Hg at the temperature of the titrant.

a is the absorption coefficient at the temperature of the titrant.

B_s is the standard barometric pressure, 760 mm Hg.

ml/mM is the volume of carbon dioxide per millimole, 22.4 ml/mM.

The part of the M table in the most useful range of temperatures is reproduced as Table 3. The entire program on cards may be obtained from the program library of the University of Texas Computation Center in Austin. Table 3 is entered with the values for the observed barometric pressure (B) and the temperature of the titrant and the barometer (t_b and t_t). Table 3 was calculated on the assumption that these two tempera-

TABLE 3

M values for observed barometric pressures between 550 and 799 mm Hg temperatures between 19.0 and 26.8° C. These values were calculated from the relationship expressed in equation (1).

These tables should be entered with the observed barometric pressure and the temperature of the titrant and the barometer. These values hold good only if a brass scale barometer is used and the temperature of the titrant and the barometer are the same.

TEMPERATURE 19.00									
550.0000	.0281782	551.0000	.0282310	552.0000	.0282838	553.0000	.0283366	554.0000	.0283895
555.0000	.0284423	556.0000	.0284951	557.0000	.0285479	558.0000	.0286007	559.0000	.0286536
560.0000	.0287064	561.0000	.0287592	562.0000	.0288120	563.0000	.0288648	564.0000	.0289177
565.0000	.0289705	566.0000	.0290233	567.0000	.0290761	568.0000	.0291289	569.0000	.0291818
570.0000	.0292346	571.0000	.0292874	572.0000	.0293402	573.0000	.0293930	574.0000	.0294459
575.0000	.0294987	576.0000	.0295515	577.0000	.0296043	578.0000	.0296571	579.0000	.0297100
580.0000	.0297628	581.0000	.0298156	582.0000	.0298684	583.0000	.0299212	584.0000	.0299741
585.0000	.0300269	586.0000	.0300797	587.0000	.0301325	588.0000	.0301853	589.0000	.0302382
590.0000	.0302910	591.0000	.0303438	592.0000	.0303966	593.0000	.0304494	594.0000	.0305023
595.0000	.0305551	596.0000	.0306079	597.0000	.0306607	598.0000	.0307135	599.0000	.0307664
600.0000	.0308192	601.0000	.0308720	602.0000	.0309248	603.0000	.0309777	604.0000	.0310305
605.0000	.0310833	606.0000	.0311361	607.0000	.0311889	608.0000	.0312418	609.0000	.0312946
610.0000	.0313474	611.0000	.0314002	612.0000	.0314530	613.0000	.0315059	614.0000	.0315587
615.0000	.0316115	616.0000	.0316643	617.0000	.0317171	618.0000	.0317700	619.0000	.0318228
620.0000	.0318756	621.0000	.0319284	622.0000	.0319812	623.0000	.0320341	624.0000	.0320869
625.0000	.0321397	626.0000	.0321925	627.0000	.0322453	628.0000	.0322982	629.0000	.0323510
630.0000	.0324038	631.0000	.0324566	632.0000	.0325094	633.0000	.0325623	634.0000	.0326151
635.0000	.0326679	636.0000	.0327207	637.0000	.0327735	638.0000	.0328264	639.0000	.0328792
640.0000	.0329320	641.0000	.0329848	642.0000	.0330376	643.0000	.0330905	644.0000	.0331433
645.0000	.0331961	646.0000	.0332489	647.0000	.0333017	648.0000	.0333546	649.0000	.0334074
650.0000	.0334602	651.0000	.0335130	652.0000	.0335658	653.0000	.0336187	654.0000	.0336715
655.0000	.0337243	656.0000	.0337771	657.0000	.0338300	658.0000	.0338828	659.0000	.0339356
660.0000	.0339884	661.0000	.0340412	662.0000	.0340941	663.0000	.0341469	664.0000	.0341997
665.0000	.0342525	666.0000	.0343053	667.0000	.0343582	668.0000	.0344110	669.0000	.0344638
670.0000	.0345166	671.0000	.0345694	672.0000	.0346223	673.0000	.0346751	674.0000	.0347279
675.0000	.0347807	676.0000	.0348335	677.0000	.0348864	678.0000	.0349392	679.0000	.0349920
680.0000	.0350448	681.0000	.0350976	682.0000	.0351505	683.0000	.0352033	684.0000	.0352561
685.0000	.0353089	686.0000	.0353617	687.0000	.0354146	688.0000	.0354674	689.0000	.0355202
690.0000	.0355730	691.0000	.0356258	692.0000	.0356787	693.0000	.0357315	694.0000	.0357843
695.0000	.0358371	696.0000	.0358899	697.0000	.0359428	698.0000	.0359956	699.0000	.0360484
700.0000	.0361012	701.0000	.0361540	702.0000	.0362069	703.0000	.0362597	704.0000	.0363125
705.0000	.0363653	706.0000	.0364181	707.0000	.0364710	708.0000	.0365238	709.0000	.0365766
710.0000	.0366294	711.0000	.0366822	712.0000	.0367351	713.0000	.0367879	714.0000	.0368407
715.0000	.0368935	716.0000	.0369464	717.0000	.0369992	718.0000	.0370520	719.0000	.0371048
720.0000	.0371576	721.0000	.0372105	722.0000	.0372633	723.0000	.0373161	724.0000	.0373689
725.0000	.0374217	726.0000	.0374746	727.0000	.0375274	728.0000	.0375802	729.0000	.0376330
730.0000	.0376858	731.0000	.0377387	732.0000	.0377915	733.0000	.0378443	734.0000	.0378971
735.0000	.0379499	736.0000	.0380028	737.0000	.0380556	738.0000	.0381084	739.0000	.0381612
740.0000	.0382140	741.0000	.0382669	742.0000	.0383197	743.0000	.0383725	744.0000	.0384253
745.0000	.0384781	746.0000	.0385310	747.0000	.0385838	748.0000	.0386366	749.0000	.0386894
750.0000	.0387422	751.0000	.0387951	752.0000	.0388479	753.0000	.0389007	754.0000	.0389535
755.0000	.0390063	756.0000	.0390592	757.0000	.0391120	758.0000	.0391648	759.0000	.0392176
760.0000	.0392704	761.0000	.0393233	762.0000	.0393761	763.0000	.0394289	764.0000	.0394817
765.0000	.0395345	766.0000	.0395874	767.0000	.0396402	768.0000	.0396930	769.0000	.0397458
770.0000	.0397986	771.0000	.0398515	772.0000	.0399043	773.0000	.0399571	774.0000	.0400099
775.0000	.0400628	776.0000	.0401156	777.0000	.0401684	778.0000	.0402212	779.0000	.0402740
780.0000	.0403269	781.0000	.0403797	782.0000	.0404325	783.0000	.0404853	784.0000	.0405381
785.0000	.0405910	786.0000	.0406438	787.0000	.0406966	788.0000	.0407494	789.0000	.0408022
790.0000	.0408551	791.0000	.0409079	792.0000	.0409607	793.0000	.0410135	794.0000	.0410663
795.0000	.0411192	796.0000	.0411720	797.0000	.0412248	798.0000	.0412776	799.0000	.0413304
TEMPERATURE 19.20									
550.0000	.0280101	551.0000	.0280626	552.0000	.0281151	553.0000	.0281677	554.0000	.0282202
555.0000	.0282727	556.0000	.0283252	557.0000	.0283778	558.0000	.0284303	559.0000	.0284828
560.0000	.0285353	561.0000	.0285879	562.0000	.0286404	563.0000	.0286929	564.0000	.0287454
565.0000	.0287980	566.0000	.0288505	567.0000	.0289030	568.0000	.0289555	569.0000	.0290081
570.0000	.0290606	571.0000	.0291131	572.0000	.0291656	573.0000	.0292182	574.0000	.0292707
575.0000	.0293232	576.0000	.0293757	577.0000	.0294283	578.0000	.0294808	579.0000	.0295333
580.0000	.0295858	581.0000	.0296384	582.0000	.0296909	583.0000	.0297434	584.0000	.0297960
585.0000	.0298485	586.0000	.0299010	587.0000	.0299535	588.0000	.0300061	589.0000	.0300586
590.0000	.0301111	591.0000	.0301636	592.0000	.0302162	593.0000	.0302687	594.0000	.0303212
595.0000	.0303737	596.0000	.0304263	597.0000	.0304788	598.0000	.0305313	599.0000	.0305838
600.0000	.0306364	601.0000	.0306889	602.0000	.0307414	603.0000	.0307939	604.0000	.0308465
605.0000	.0308990	606.0000	.0309515	607.0000	.0310040	608.0000	.0310566	609.0000	.0311091
610.0000	.0311616	611.0000	.0312141	612.0000	.0312667	613.0000	.0313192	614.0000	.0313717
615.0000	.0314243	616.0000	.0314768	617.0000	.0315293	618.0000	.0315818	619.0000	.0316344
620.0000	.0316869	621.0000	.0317394	622.0000	.0317919	623.0000	.0318445	624.0000	.0318970
625.0000	.0319495	626.0000	.0320020	627.0000	.0320546	628.0000	.0321071	629.0000	.0321596
630.0000	.0322121	631.0000	.0322647	632.0000	.0323172	633.0000	.0323697	634.0000	.0324222
635.0000	.0324748	636.0000	.0325273	637.0000	.0325798	638.0000	.0326323	639.0000	.0326849
640.0000	.0327374	641.0000	.0327899	642.0000	.0328424	643.0000	.0328950	644.0000	.0329475
645.0000	.0330000	646.0000	.0330526	647.0000	.0331051	648.0000	.0331576	649.0000	.0332101
650.0000	.0332627	651.0000	.0333152	652.0000	.0333677	653.0000	.0334202	654.0000	.0334728
655.0000	.0335253	656.0000	.0335778	657.0000	.0336303	658.0000	.0336829	659.0000	.0337354
660.0000	.0337879	661.0000	.0338404	662.0000	.0338930	663.0000	.0339455	664.0000	.0339980
665.0000	.0340505	666.0000	.0341031	667.0000	.0341556	668.0000	.0342081	669.0000	.0342606
670.0000	.0343132	671.0000	.0343657	672.0000	.0344182	673.0000	.0344708	674.0000	.0345233
675.0000	.0345758	676.0000	.0346283	677.0000	.0346809	678.0000	.0347334	679.0000	.0347859
680.0000	.0348384	681.0000	.0348910	682.0000	.0349435	683.0000	.0349960	684.0000	.0350485
685.0000	.0351011	686.0000	.0351536	687.0000	.0352061	688.0000	.0352586	689.0000	.0353112
690.0000	.0353637	691.0000	.0354162	692.0000	.0354687	693.0000	.0355213	694.0000	.0355738
695.0000	.0356263	696.0000	.0356788	697.0000	.0357314	698.0000	.0357839	699.0000	.0358364
700.0000	.0358889	701.0000	.0359415	702.0000	.0359940	703.0000	.0360465	704.0000	.0360991
705.0000	.0361516	706.0000	.0362041	707.0000	.0362566	708.0000	.0363092	709.0000	.0363617
710.0000	.0364142	711.0000	.0364667	712.0000	.0365193	713.0000	.0365718	714.0000	.0366243
715.0000	.0366768	716.0000	.0367294	717.0000	.0367819	718.0000	.0368344	719.0000	.0368869
720.0000	.0369395	721.0000	.0369920	722.0000	.0370445	723.0000	.0370970	724.0000	.0371496
725.0000	.0372071	726.0000	.0372596	727.0000	.0373121	728.0000	.0373646	729.0000	.0374172
730.0000	.0374647	731.0000	.0375172	732.0000	.0375698	733.0000	.0376223	734.0000	.0376748
735.0000	.0377274	736.0000	.0377799	737.0000	.0378324	738.0000	.0378849	739.0000	.0379375
740.0000	.0379900	741.0000	.0380425	742.0000	.0380950	743.0000	.0381476	744.0000	.0382001
745.0000	.0382526	746.0000	.0383051	747.0000	.0383577	748.0000	.0384102	749.0000	.0384627
750.0000	.0385152	751.0000	.0385678	752.0000	.0386203	753.0000	.0386728	754.0000	.0387253
755.0000	.0387779	756.0000	.0388304	757.0000	.0388829	758.0000	.0389354	759.0000	.03

TABLE 3—Continued

TEMPERATURE		19.40							
550.0000	.0278421	551.0000	.0278943	552.0000	.0279465	553.0000	.0279987	554.0000	.0280510
555.0000	.0281032	556.0000	.0281554	557.0000	.0282077	558.0000	.0282599	559.0000	.0283121
560.0000	.0283644	561.0000	.0284166	562.0000	.0284688	563.0000	.0285211	564.0000	.0285733
565.0000	.0286255	566.0000	.0286778	567.0000	.0287300	568.0000	.0287822	569.0000	.0288344
570.0000	.0288867	571.0000	.0289389	572.0000	.0289911	573.0000	.0290434	574.0000	.0290956
575.0000	.0291478	576.0000	.0292001	577.0000	.0292523	578.0000	.0293045	579.0000	.0293568
580.0000	.0294090	581.0000	.0294612	582.0000	.0295135	583.0000	.0295657	584.0000	.0296179
585.0000	.0296701	586.0000	.0297224	587.0000	.0297746	588.0000	.0298268	589.0000	.0298791
590.0000	.0299313	591.0000	.0299835	592.0000	.0300358	593.0000	.0300880	594.0000	.0301402
595.0000	.0301925	596.0000	.0302447	597.0000	.0302969	598.0000	.0303492	599.0000	.0304014
600.0000	.0304536	601.0000	.0305059	602.0000	.0305581	603.0000	.0306103	604.0000	.0306625
605.0000	.0307148	606.0000	.0307670	607.0000	.0308192	608.0000	.0308715	609.0000	.0309237
610.0000	.0309759	611.0000	.0310282	612.0000	.0310804	613.0000	.0311326	614.0000	.0311849
615.0000	.0312371	616.0000	.0312893	617.0000	.0313416	618.0000	.0313938	619.0000	.0314460
620.0000	.0314982	621.0000	.0315505	622.0000	.0316027	623.0000	.0316549	624.0000	.0317072
625.0000	.0317594	626.0000	.0318116	627.0000	.0318639	628.0000	.0319161	629.0000	.0319683
630.0000	.0320206	631.0000	.0320728	632.0000	.0321250	633.0000	.0321773	634.0000	.0322295
635.0000	.0322817	636.0000	.0323339	637.0000	.0323862	638.0000	.0324384	639.0000	.0324906
640.0000	.0325429	641.0000	.0325951	642.0000	.0326473	643.0000	.0326996	644.0000	.0327518
645.0000	.0328040	646.0000	.0328563	647.0000	.0329085	648.0000	.0329607	649.0000	.0330130
650.0000	.0330652	651.0000	.0331174	652.0000	.0331697	653.0000	.0332219	654.0000	.0332741
655.0000	.0333263	656.0000	.0333786	657.0000	.0334308	658.0000	.0334830	659.0000	.0335353
660.0000	.0335875	661.0000	.0336397	662.0000	.0336920	663.0000	.0337442	664.0000	.0337964
665.0000	.0338487	666.0000	.0339009	667.0000	.0339531	668.0000	.0340054	669.0000	.0340576
670.0000	.0341098	671.0000	.0341620	672.0000	.0342143	673.0000	.0342665	674.0000	.0343187
675.0000	.0343710	676.0000	.0344232	677.0000	.0344754	678.0000	.0345277	679.0000	.0345799
680.0000	.0346321	681.0000	.0346844	682.0000	.0347366	683.0000	.0347888	684.0000	.0348411
685.0000	.0348933	686.0000	.0349455	687.0000	.0349977	688.0000	.0350500	689.0000	.0351022
690.0000	.0351544	691.0000	.0352067	692.0000	.0352589	693.0000	.0353111	694.0000	.0353634
695.0000	.0354156	696.0000	.0354678	697.0000	.0355201	698.0000	.0355723	699.0000	.0356245
700.0000	.0356768	701.0000	.0357290	702.0000	.0357812	703.0000	.0358334	704.0000	.0358857
705.0000	.0359379	706.0000	.0359901	707.0000	.0360424	708.0000	.0360946	709.0000	.0361468
710.0000	.0361991	711.0000	.0362513	712.0000	.0363035	713.0000	.0363558	714.0000	.0364080
715.0000	.0364602	716.0000	.0365125	717.0000	.0365647	718.0000	.0366169	719.0000	.0366692
720.0000	.0367214	721.0000	.0367736	722.0000	.0368258	723.0000	.0368781	724.0000	.0369303
725.0000	.0369825	726.0000	.0370348	727.0000	.0370870	728.0000	.0371392	729.0000	.0371915
730.0000	.0372437	731.0000	.0372959	732.0000	.0373482	733.0000	.0374004	734.0000	.0374526
735.0000	.0375049	736.0000	.0375571	737.0000	.0376093	738.0000	.0376615	739.0000	.0377138
740.0000	.0377660	741.0000	.0378182	742.0000	.0378705	743.0000	.0379227	744.0000	.0379749
745.0000	.0380272	746.0000	.0380794	747.0000	.0381316	748.0000	.0381839	749.0000	.0382361
750.0000	.0382883	751.0000	.0383406	752.0000	.0383928	753.0000	.0384450	754.0000	.0384972
755.0000	.0385495	756.0000	.0386017	757.0000	.0386539	758.0000	.0387062	759.0000	.0387584
760.0000	.0388106	761.0000	.0388629	762.0000	.0389151	763.0000	.0389673	764.0000	.0390196
765.0000	.0390718	766.0000	.0391240	767.0000	.0391763	768.0000	.0392285	769.0000	.0392807
770.0000	.0393329	771.0000	.0393852	772.0000	.0394374	773.0000	.0394896	774.0000	.0395419
775.0000	.0395941	776.0000	.0396463	777.0000	.0396986	778.0000	.0397508	779.0000	.0398030
780.0000	.0398553	781.0000	.0399075	782.0000	.0399597	783.0000	.0400120	784.0000	.0400642
785.0000	.0401164	786.0000	.0401687	787.0000	.0402209	788.0000	.0402731	789.0000	.0403253
790.0000	.0403776	791.0000	.0404298	792.0000	.0404820	793.0000	.0405343	794.0000	.0405865
795.0000	.0406387	796.0000	.0406910	797.0000	.0407432	798.0000	.0407954	799.0000	.0408477

TEMPERATURE		19.60							
550.0000	.0276741	551.0000	.0277260	552.0000	.0277779	553.0000	.0278299	554.0000	.0278818
555.0000	.0279337	556.0000	.0279857	557.0000	.0280376	558.0000	.0280896	559.0000	.0281415
560.0000	.0281934	561.0000	.0282454	562.0000	.0282973	563.0000	.0283492	564.0000	.0284012
565.0000	.0284531	566.0000	.0285051	567.0000	.0285570	568.0000	.0286089	569.0000	.0286609
570.0000	.0287128	571.0000	.0287647	572.0000	.0288167	573.0000	.0288686	574.0000	.0289205
575.0000	.0289725	576.0000	.0290244	577.0000	.0290764	578.0000	.0291283	579.0000	.0291802
580.0000	.0292322	581.0000	.0292841	582.0000	.0293360	583.0000	.0293880	584.0000	.0294399
585.0000	.0294919	586.0000	.0295438	587.0000	.0295957	588.0000	.0296477	589.0000	.0296996
590.0000	.0297515	591.0000	.0298035	592.0000	.0298554	593.0000	.0299073	594.0000	.0299593
595.0000	.0300112	596.0000	.0300632	597.0000	.0301151	598.0000	.0301670	599.0000	.0302190
600.0000	.0302709	601.0000	.0303228	602.0000	.0303748	603.0000	.0304267	604.0000	.0304787
605.0000	.0305306	606.0000	.0305825	607.0000	.0306345	608.0000	.0306864	609.0000	.0307383
610.0000	.0307903	611.0000	.0308422	612.0000	.0308941	613.0000	.0309461	614.0000	.0309980
615.0000	.0310500	616.0000	.0311019	617.0000	.0311538	618.0000	.0312058	619.0000	.0312577
620.0000	.0313096	621.0000	.0313616	622.0000	.0314135	623.0000	.0314655	624.0000	.0315174
625.0000	.0315693	626.0000	.0316213	627.0000	.0316732	628.0000	.0317251	629.0000	.0317771
630.0000	.0318290	631.0000	.0318809	632.0000	.0319329	633.0000	.0319848	634.0000	.0320368
635.0000	.0320887	636.0000	.0321406	637.0000	.0321926	638.0000	.0322445	639.0000	.0322964
640.0000	.0323484	641.0000	.0324003	642.0000	.0324523	643.0000	.0325042	644.0000	.0325561
645.0000	.0326081	646.0000	.0326600	647.0000	.0327119	648.0000	.0327639	649.0000	.0328158
650.0000	.0328677	651.0000	.0329197	652.0000	.0329716	653.0000	.0330236	654.0000	.0330755
655.0000	.0331274	656.0000	.0331794	657.0000	.0332313	658.0000	.0332832	659.0000	.0333352
660.0000	.0333871	661.0000	.0334391	662.0000	.0334910	663.0000	.0335429	664.0000	.0335949
665.0000	.0336468	666.0000	.0336987	667.0000	.0337507	668.0000	.0338026	669.0000	.0338546
670.0000	.0339065	671.0000	.0339584	672.0000	.0340104	673.0000	.0340623	674.0000	.0341142
675.0000	.0341662	676.0000	.0342181	677.0000	.0342700	678.0000	.0343220	679.0000	.0343739
680.0000	.0344259	681.0000	.0344778	682.0000	.0345297	683.0000	.0345817	684.0000	.0346336
685.0000	.0346855	686.0000	.0347375	687.0000	.0347894	688.0000	.0348414	689.0000	.0348933
690.0000	.0349452	691.0000	.0349972	692.0000	.0350491	693.0000	.0351010	694.0000	.0351530
695.0000	.0352049	696.0000	.0352568	697.0000	.0353088	698.0000	.0353607	699.0000	.0354127
700.0000	.0354646	701.0000	.0355165	702.0000	.0355685	703.0000	.0356204	704.0000	.0356723
705.0000	.0357243	706.0000	.0357762	707.0000	.0358282	708.0000	.0358801	709.0000	.0359320
710.0000	.0359840	711.0000	.0360359	712.0000	.0360878	713.0000	.0361398	714.0000	.0361917
715.0000	.0362436	716.0000	.0362956	717.0000	.0363475	718.0000	.0363995	719.0000	.0364514
720.0000	.0365033	721.0000	.0365553	722.0000	.0366072	723.0000	.0366591	724.0000	.0367111
725.0000	.0367630	726.0000	.0368150	727.0000	.0368669	728.0000	.0369188	729.0000	.0369708
730.0000	.0370227	731.0000	.0370746	732.0000	.0371266	733.0000	.0371785	734.0000	.0372304
735.0000	.0372824	736.0000	.0373343	737.0000	.0373863	738.0000	.0374382	739.0000	.0374901
740.0000	.0375421	741.0000	.0375940	742.0000	.0376459	743.0000	.0376979	744.0000	.0377498
745.0000	.0378018	746.0000	.0378537	747.0000	.0379056	748.0000	.0379576	749.0000	.0380095
750.0000	.0380614	751.0000	.0381134	752.0000	.0381653	753.0000	.0382172	754.0000	.0382692
755.0000	.0383211	756.0000	.0383731	757.0000	.0384250	758.0000	.0384769	759.0000	.0385289
760.0000	.038580								

TABLE 3—Continued

TEMPERATURE	19.80								
550.0000	.0275372	551.0000	.0275889	552.0000	.0276406	553.0000	.0276923	554.0000	.0277440
555.0000	.0277957	556.0000	.0278474	557.0000	.0278991	558.0000	.0279508	559.0000	.0280025
560.0000	.0280542	561.0000	.0281059	562.0000	.0281576	563.0000	.0282093	564.0000	.0282610
565.0000	.0283128	566.0000	.0283645	567.0000	.0284162	568.0000	.0284679	569.0000	.0285196
570.0000	.0285713	571.0000	.0286230	572.0000	.0286747	573.0000	.0287264	574.0000	.0287781
575.0000	.0288298	576.0000	.0288815	577.0000	.0289332	578.0000	.0289849	579.0000	.0290366
580.0000	.0290883	581.0000	.0291400	582.0000	.0291917	583.0000	.0292434	584.0000	.0292951
585.0000	.0293468	586.0000	.0293985	587.0000	.0294502	588.0000	.0295019	589.0000	.0295536
590.0000	.0296053	591.0000	.0296570	592.0000	.0297087	593.0000	.0297604	594.0000	.0298121
595.0000	.0298638	596.0000	.0299155	597.0000	.0299672	598.0000	.0300189	599.0000	.0300706
600.0000	.0301223	601.0000	.0301740	602.0000	.0302257	603.0000	.0302774	604.0000	.0303291
605.0000	.0303808	606.0000	.0304325	607.0000	.0304842	608.0000	.0305359	609.0000	.0305876
610.0000	.0306393	611.0000	.0306910	612.0000	.0307427	613.0000	.0307944	614.0000	.0308461
615.0000	.0308978	616.0000	.0309495	617.0000	.0310012	618.0000	.0310529	619.0000	.0311046
620.0000	.0311563	621.0000	.0312080	622.0000	.0312597	623.0000	.0313114	624.0000	.0313631
625.0000	.0314148	626.0000	.0314665	627.0000	.0315182	628.0000	.0315699	629.0000	.0316216
630.0000	.0316733	631.0000	.0317250	632.0000	.0317767	633.0000	.0318284	634.0000	.0318801
635.0000	.0319318	636.0000	.0319835	637.0000	.0320352	638.0000	.0320869	639.0000	.0321386
640.0000	.0321903	641.0000	.0322420	642.0000	.0322937	643.0000	.0323454	644.0000	.0323971
645.0000	.0324488	646.0000	.0325005	647.0000	.0325522	648.0000	.0326039	649.0000	.0326556
650.0000	.0327073	651.0000	.0327590	652.0000	.0328107	653.0000	.0328624	654.0000	.0329141
655.0000	.0329658	656.0000	.0330175	657.0000	.0330692	658.0000	.0331209	659.0000	.0331726
660.0000	.0332243	661.0000	.0332760	662.0000	.0333277	663.0000	.0333794	664.0000	.0334311
665.0000	.0334828	666.0000	.0335345	667.0000	.0335862	668.0000	.0336379	669.0000	.0336896
670.0000	.0337414	671.0000	.0337931	672.0000	.0338448	673.0000	.0338965	674.0000	.0339482
675.0000	.0339999	676.0000	.0340516	677.0000	.0341033	678.0000	.0341550	679.0000	.0342067
680.0000	.0342584	681.0000	.0343101	682.0000	.0343618	683.0000	.0344135	684.0000	.0344652
685.0000	.0345169	686.0000	.0345686	687.0000	.0346203	688.0000	.0346720	689.0000	.0347237
690.0000	.0347754	691.0000	.0348271	692.0000	.0348788	693.0000	.0349305	694.0000	.0349822
695.0000	.0350339	696.0000	.0350856	697.0000	.0351373	698.0000	.0351890	699.0000	.0352407
700.0000	.0352924	701.0000	.0353441	702.0000	.0353958	703.0000	.0354475	704.0000	.0354992
705.0000	.0355509	706.0000	.0356026	707.0000	.0356543	708.0000	.0357060	709.0000	.0357577
710.0000	.0358094	711.0000	.0358611	712.0000	.0359128	713.0000	.0359645	714.0000	.0360162
715.0000	.0360679	716.0000	.0361196	717.0000	.0361713	718.0000	.0362230	719.0000	.0362747
720.0000	.0363264	721.0000	.0363781	722.0000	.0364298	723.0000	.0364815	724.0000	.0365332
725.0000	.0365849	726.0000	.0366366	727.0000	.0366883	728.0000	.0367400	729.0000	.0367917
730.0000	.0368434	731.0000	.0368951	732.0000	.0369468	733.0000	.0369985	734.0000	.0370502
735.0000	.0371019	736.0000	.0371536	737.0000	.0372053	738.0000	.0372570	739.0000	.0373087
740.0000	.0373604	741.0000	.0374121	742.0000	.0374638	743.0000	.0375155	744.0000	.0375672
745.0000	.0376189	746.0000	.0376706	747.0000	.0377223	748.0000	.0377740	749.0000	.0378257
750.0000	.0378774	751.0000	.0379291	752.0000	.0379808	753.0000	.0380325	754.0000	.0380842
755.0000	.0381359	756.0000	.0381876	757.0000	.0382393	758.0000	.0382910	759.0000	.0383427
760.0000	.0383944	761.0000	.0384461	762.0000	.0384978	763.0000	.0385495	764.0000	.0386012
765.0000	.0386529	766.0000	.0387046	767.0000	.0387563	768.0000	.0388080	769.0000	.0388597
770.0000	.0389115	771.0000	.0389632	772.0000	.0390149	773.0000	.0390666	774.0000	.0391183
775.0000	.0391700	776.0000	.0392217	777.0000	.0392734	778.0000	.0393251	779.0000	.0393768
780.0000	.0394285	781.0000	.0394802	782.0000	.0395319	783.0000	.0395836	784.0000	.0396353
785.0000	.0396870	786.0000	.0397387	787.0000	.0397904	788.0000	.0398421	789.0000	.0398938
790.0000	.0399455	791.0000	.0399972	792.0000	.0400489	793.0000	.0401006	794.0000	.0401523
795.0000	.0402040	796.0000	.0402557	797.0000	.0403074	798.0000	.0403591	799.0000	.0404108

TEMPERATURE	20.00								
550.0000	.0273692	551.0000	.0274207	552.0000	.0274721	553.0000	.0275235	554.0000	.0275749
555.0000	.0276263	556.0000	.0276777	557.0000	.0277291	558.0000	.0277805	559.0000	.0278319
560.0000	.0278833	561.0000	.0279347	562.0000	.0279861	563.0000	.0280375	564.0000	.0280889
565.0000	.0281403	566.0000	.0281917	567.0000	.0282432	568.0000	.0282946	569.0000	.0283460
570.0000	.0283974	571.0000	.0284488	572.0000	.0285002	573.0000	.0285516	574.0000	.0286030
575.0000	.0286544	576.0000	.0287058	577.0000	.0287572	578.0000	.0288086	579.0000	.0288600
580.0000	.0289114	581.0000	.0289628	582.0000	.0290143	583.0000	.0290657	584.0000	.0291171
585.0000	.0291685	586.0000	.0292199	587.0000	.0292713	588.0000	.0293227	589.0000	.0293741
590.0000	.0294255	591.0000	.0294769	592.0000	.0295283	593.0000	.0295797	594.0000	.0296311
595.0000	.0296825	596.0000	.0297339	597.0000	.0297854	598.0000	.0298368	599.0000	.0298882
600.0000	.0299396	601.0000	.0299910	602.0000	.0300424	603.0000	.0300938	604.0000	.0301452
605.0000	.0301966	606.0000	.0302480	607.0000	.0302994	608.0000	.0303508	609.0000	.0304022
610.0000	.0304536	611.0000	.0305050	612.0000	.0305564	613.0000	.0306079	614.0000	.0306593
615.0000	.0307107	616.0000	.0307621	617.0000	.0308135	618.0000	.0308649	619.0000	.0309163
620.0000	.0309677	621.0000	.0310191	622.0000	.0310705	623.0000	.0311219	624.0000	.0311733
625.0000	.0312247	626.0000	.0312761	627.0000	.0313275	628.0000	.0313790	629.0000	.0314304
630.0000	.0314818	631.0000	.0315332	632.0000	.0315846	633.0000	.0316360	634.0000	.0316874
635.0000	.0317388	636.0000	.0317902	637.0000	.0318416	638.0000	.0318930	639.0000	.0319444
640.0000	.0319958	641.0000	.0320472	642.0000	.0320986	643.0000	.0321501	644.0000	.0322015
645.0000	.0322529	646.0000	.0323043	647.0000	.0323557	648.0000	.0324071	649.0000	.0324585
650.0000	.0325099	651.0000	.0325613	652.0000	.0326127	653.0000	.0326641	654.0000	.0327155
655.0000	.0327669	656.0000	.0328183	657.0000	.0328697	658.0000	.0329212	659.0000	.0329726
660.0000	.0330240	661.0000	.0330754	662.0000	.0331268	663.0000	.0331782	664.0000	.0332296
665.0000	.0332810	666.0000	.0333324	667.0000	.0333838	668.0000	.0334352	669.0000	.0334866
670.0000	.0335380	671.0000	.0335894	672.0000	.0336408	673.0000	.0336922	674.0000	.0337437
675.0000	.0337951	676.0000	.0338465	677.0000	.0338979	678.0000	.0339493	679.0000	.0340007
680.0000	.0340521	681.0000	.0341035	682.0000	.0341549	683.0000	.0342063	684.0000	.0342577
685.0000	.0343091	686.0000	.0343605	687.0000	.0344119	688.0000	.0344633	689.0000	.0345148
690.0000	.0345662	691.0000	.0346176	692.0000	.0346690	693.0000	.0347204	694.0000	.0347718
695.0000	.0348232	696.0000	.0348746	697.0000	.0349260	698.0000	.0349774	699.0000	.0350288
700.0000	.0350802	701.0000	.0351316	702.0000	.0351830	703.0000	.0352344	704.0000	.0352859
705.0000	.0353373	706.0000	.0353887	707.0000	.0354401	708.0000	.0354915	709.0000	.0355429
710.0000	.0355943	711.0000	.0356457	712.0000	.0356971	713.0000	.0357485	714.0000	.0357999
715.0000	.0358513	716.0000	.0359027	717.0000	.0359541	718.0000	.0360055	719.0000	.0360569
720.0000	.0361084	721.0000	.0361598	722.0000	.0362112	723.0000	.0362626	724.0000	.0363140
725.0000	.0363654	726.0000	.0364168	727.0000	.0364682	728.0000	.0365196	729.0000	.0365710
730.0000	.0366224	731.0000	.0366738	732.0000	.0367252	733.0000	.0367766	734.0000	.0368280
735.0000	.0368795	736.0000	.0369309	737.0000	.0369823	738.0000	.0370337	739.0000	.0370851
740.0000	.0371365	741.0000	.0371879	742.0000	.0372393	743.0000	.0372907	744.0000	.0373421
745.0000	.0373935	746.0000	.0374449	747.0000	.0374963	748.0000	.0375477	749.0000	.0375991
750.0000	.0376506	751.0000	.0377020	752.0000	.0377534	753.0000	.0378048	754.0000	.0378562
755.0000	.0379076	756.0000	.0379590	757.0000	.0380104	758.0000	.0380618	759.0000	.0381132
760.0000	.0381646	761.0000	.0382160	762.0000	.0382674	763.0000	.0383188	764.0000	.0383702
765.0000	.0384217	766.0							

TABLE 3—Continued

TEMPERATURE 20.20									
550.0000	.0272013	551.0000	.0272524	552.0000	.0273035	553.0000	.0273546	554.0000	.0274057
555.0000	.0274568	556.0000	.0275080	557.0000	.0275591	558.0000	.0276102	559.0000	.0276613
560.0000	.0277124	561.0000	.0277635	562.0000	.0278146	563.0000	.0278657	564.0000	.0279169
565.0000	.0279680	566.0000	.0280191	567.0000	.0280702	568.0000	.0281213	569.0000	.0281724
570.0000	.0282235	571.0000	.0282746	572.0000	.0283258	573.0000	.0283769	574.0000	.0284280
575.0000	.0284791	576.0000	.0285302	577.0000	.0285813	578.0000	.0286324	579.0000	.0286835
580.0000	.0287346	581.0000	.0287858	582.0000	.0288369	583.0000	.0288880	584.0000	.0289391
585.0000	.0289902	586.0000	.0290413	587.0000	.0290924	588.0000	.0291435	589.0000	.0291947
590.0000	.0292458	591.0000	.0292969	592.0000	.0293480	593.0000	.0293991	594.0000	.0294502
595.0000	.0295013	596.0000	.0295524	597.0000	.0296036	598.0000	.0296547	599.0000	.0297058
600.0000	.0297569	601.0000	.0298080	602.0000	.0298591	603.0000	.0299102	604.0000	.0299613
605.0000	.0300125	606.0000	.0300636	607.0000	.0301147	608.0000	.0301658	609.0000	.0302169
610.0000	.0302680	611.0000	.0303191	612.0000	.0303702	613.0000	.0304214	614.0000	.0304725
615.0000	.0305236	616.0000	.0305747	617.0000	.0306258	618.0000	.0306769	619.0000	.0307280
620.0000	.0307791	621.0000	.0308302	622.0000	.0308814	623.0000	.0309325	624.0000	.0309836
625.0000	.0310347	626.0000	.0310858	627.0000	.0311369	628.0000	.0311880	629.0000	.0312391
630.0000	.0312903	631.0000	.0313414	632.0000	.0313925	633.0000	.0314436	634.0000	.0314947
635.0000	.0315458	636.0000	.0315969	637.0000	.0316480	638.0000	.0316992	639.0000	.0317503
640.0000	.0318014	641.0000	.0318525	642.0000	.0319036	643.0000	.0319547	644.0000	.0320058
645.0000	.0320569	646.0000	.0321081	647.0000	.0321592	648.0000	.0322103	649.0000	.0322614
650.0000	.0323125	651.0000	.0323636	652.0000	.0324147	653.0000	.0324658	654.0000	.0325169
655.0000	.0325681	656.0000	.0326192	657.0000	.0326703	658.0000	.0327214	659.0000	.0327725
660.0000	.0328236	661.0000	.0328747	662.0000	.0329258	663.0000	.0329770	664.0000	.0330281
665.0000	.0330792	666.0000	.0331303	667.0000	.0331814	668.0000	.0332325	669.0000	.0332836
670.0000	.0333347	671.0000	.0333859	672.0000	.0334370	673.0000	.0334881	674.0000	.0335392
675.0000	.0335903	676.0000	.0336414	677.0000	.0336925	678.0000	.0337436	679.0000	.0337948
680.0000	.0338459	681.0000	.0338970	682.0000	.0339481	683.0000	.0339992	684.0000	.0340503
685.0000	.0341014	686.0000	.0341525	687.0000	.0342036	688.0000	.0342548	689.0000	.0343059
690.0000	.0343570	691.0000	.0344081	692.0000	.0344592	693.0000	.0345103	694.0000	.0345614
695.0000	.0346125	696.0000	.0346637	697.0000	.0347148	698.0000	.0347659	699.0000	.0348170
700.0000	.0348681	701.0000	.0349192	702.0000	.0349703	703.0000	.0350214	704.0000	.0350726
705.0000	.0351237	706.0000	.0351748	707.0000	.0352259	708.0000	.0352770	709.0000	.0353281
710.0000	.0353792	711.0000	.0354303	712.0000	.0354815	713.0000	.0355326	714.0000	.0355837
715.0000	.0356348	716.0000	.0356859	717.0000	.0357370	718.0000	.0357881	719.0000	.0358392
720.0000	.0358903	721.0000	.0359415	722.0000	.0359926	723.0000	.0360437	724.0000	.0360948
725.0000	.0361459	726.0000	.0361970	727.0000	.0362481	728.0000	.0362992	729.0000	.0363504
730.0000	.0364015	731.0000	.0364526	732.0000	.0365037	733.0000	.0365548	734.0000	.0366059
735.0000	.0366570	736.0000	.0367081	737.0000	.0367593	738.0000	.0368104	739.0000	.0368615
740.0000	.0369126	741.0000	.0369637	742.0000	.0370148	743.0000	.0370659	744.0000	.0371170
745.0000	.0371682	746.0000	.0372193	747.0000	.0372704	748.0000	.0373215	749.0000	.0373726
750.0000	.0374237	751.0000	.0374748	752.0000	.0375259	753.0000	.0375770	754.0000	.0376282
755.0000	.0376793	756.0000	.0377304	757.0000	.0377815	758.0000	.0378326	759.0000	.0378837
760.0000	.0379348	761.0000	.0379859	762.0000	.0380371	763.0000	.0380882	764.0000	.0381393
765.0000	.0381904	766.0000	.0382415	767.0000	.0382926	768.0000	.0383437	769.0000	.0383948
770.0000	.0384460	771.0000	.0384971	772.0000	.0385482	773.0000	.0385993	774.0000	.0386504
775.0000	.0387015	776.0000	.0387526	777.0000	.0388037	778.0000	.0388549	779.0000	.0389060
780.0000	.0389571	781.0000	.0390082	782.0000	.0390593	783.0000	.0391104	784.0000	.0391615
785.0000	.0392126	786.0000	.0392637	787.0000	.0393149	788.0000	.0393660	789.0000	.0394171
790.0000	.0394682	791.0000	.0395193	792.0000	.0395704	793.0000	.0396215	794.0000	.0396726
795.0000	.0397238	796.0000	.0397749	797.0000	.0398260	798.0000	.0398771	799.0000	.0399282

TEMPERATURE 20.40									
550.0000	.0270333	551.0000	.0270841	552.0000	.0271349	553.0000	.0271858	554.0000	.0272366
555.0000	.0272874	556.0000	.0273382	557.0000	.0273890	558.0000	.0274399	559.0000	.0274907
560.0000	.0275415	561.0000	.0275923	562.0000	.0276431	563.0000	.0276939	564.0000	.0277448
565.0000	.0277956	566.0000	.0278464	567.0000	.0278972	568.0000	.0279480	569.0000	.0279989
570.0000	.0280497	571.0000	.0281005	572.0000	.0281513	573.0000	.0282021	574.0000	.0282529
575.0000	.0283038	576.0000	.0283546	577.0000	.0284054	578.0000	.0284562	579.0000	.0285070
580.0000	.0285578	581.0000	.0286087	582.0000	.0286595	583.0000	.0287103	584.0000	.0287611
585.0000	.0288119	586.0000	.0288628	587.0000	.0289136	588.0000	.0289644	589.0000	.0290152
590.0000	.0290660	591.0000	.0291168	592.0000	.0291677	593.0000	.0292185	594.0000	.0292693
595.0000	.0293201	596.0000	.0293709	597.0000	.0294217	598.0000	.0294726	599.0000	.0295234
600.0000	.0295742	601.0000	.0296250	602.0000	.0296758	603.0000	.0297267	604.0000	.0297775
605.0000	.0298283	606.0000	.0298791	607.0000	.0299299	608.0000	.0299807	609.0000	.0300316
610.0000	.0300824	611.0000	.0301332	612.0000	.0301840	613.0000	.0302348	614.0000	.0302856
615.0000	.0303365	616.0000	.0303873	617.0000	.0304381	618.0000	.0304889	619.0000	.0305397
620.0000	.0305906	621.0000	.0306414	622.0000	.0306922	623.0000	.0307430	624.0000	.0307938
625.0000	.0308446	626.0000	.0308955	627.0000	.0309463	628.0000	.0309971	629.0000	.0310479
630.0000	.0310987	631.0000	.0311496	632.0000	.0312004	633.0000	.0312512	634.0000	.0313020
635.0000	.0313528	636.0000	.0314036	637.0000	.0314545	638.0000	.0315053	639.0000	.0315561
640.0000	.0316069	641.0000	.0316577	642.0000	.0317085	643.0000	.0317594	644.0000	.0318102
645.0000	.0318610	646.0000	.0319118	647.0000	.0319626	648.0000	.0320135	649.0000	.0320643
650.0000	.0321151	651.0000	.0321659	652.0000	.0322167	653.0000	.0322675	654.0000	.0323184
655.0000	.0323692	656.0000	.0324200	657.0000	.0324708	658.0000	.0325216	659.0000	.0325724
660.0000	.0326233	661.0000	.0326741	662.0000	.0327249	663.0000	.0327757	664.0000	.0328265
665.0									

TABLE 3—Continued

TEMPERATURE	20.60								
550.0000	.0268965	551.0000	.0269471	552.0000	.0269977	553.0000	.0270483	554.0000	.0270988
555.0000	.0271494	556.0000	.0272000	557.0000	.0272506	558.0000	.0273012	559.0000	.0273517
560.0000	.0274023	561.0000	.0274529	562.0000	.0275035	563.0000	.0275541	564.0000	.0276047
565.0000	.0276552	566.0000	.0277058	567.0000	.0277564	568.0000	.0278070	569.0000	.0278576
570.0000	.0279081	571.0000	.0279587	572.0000	.0280093	573.0000	.0280599	574.0000	.0281105
575.0000	.0281611	576.0000	.0282116	577.0000	.0282622	578.0000	.0283128	579.0000	.0283634
580.0000	.0284140	581.0000	.0284646	582.0000	.0285151	583.0000	.0285657	584.0000	.0286163
585.0000	.0286669	586.0000	.0287175	587.0000	.0287680	588.0000	.0288186	589.0000	.0288692
590.0000	.0289198	591.0000	.0289704	592.0000	.0290210	593.0000	.0290715	594.0000	.0291221
595.0000	.0291727	596.0000	.0292233	597.0000	.0292739	598.0000	.0293244	599.0000	.0293750
600.0000	.0294256	601.0000	.0294762	602.0000	.0295268	603.0000	.0295774	604.0000	.0296279
605.0000	.0296785	606.0000	.0297291	607.0000	.0297797	608.0000	.0298303	609.0000	.0298808
610.0000	.0299314	611.0000	.0299820	612.0000	.0300326	613.0000	.0300832	614.0000	.0301338
615.0000	.0301843	616.0000	.0302349	617.0000	.0302855	618.0000	.0303361	619.0000	.0303867
620.0000	.0304372	621.0000	.0304878	622.0000	.0305384	623.0000	.0305890	624.0000	.0306396
625.0000	.0306902	626.0000	.0307407	627.0000	.0307913	628.0000	.0308419	629.0000	.0308925
630.0000	.0309431	631.0000	.0309936	632.0000	.0310442	633.0000	.0310948	634.0000	.0311454
635.0000	.0311960	636.0000	.0312466	637.0000	.0312971	638.0000	.0313477	639.0000	.0313983
640.0000	.0314489	641.0000	.0314995	642.0000	.0315500	643.0000	.0316006	644.0000	.0316512
645.0000	.0317018	646.0000	.0317524	647.0000	.0318030	648.0000	.0318535	649.0000	.0319041
650.0000	.0319547	651.0000	.0320053	652.0000	.0320559	653.0000	.0321064	654.0000	.0321570
655.0000	.0322076	656.0000	.0322582	657.0000	.0323088	658.0000	.0323594	659.0000	.0324099
660.0000	.0324605	661.0000	.0325111	662.0000	.0325617	663.0000	.0326123	664.0000	.0326628
665.0000	.0327134	666.0000	.0327640	667.0000	.0328146	668.0000	.0328652	669.0000	.0329158
670.0000	.0329663	671.0000	.0330169	672.0000	.0330675	673.0000	.0331181	674.0000	.0331687
675.0000	.0332192	676.0000	.0332698	677.0000	.0333204	678.0000	.0333710	679.0000	.0334216
680.0000	.0334722	681.0000	.0335227	682.0000	.0335733	683.0000	.0336239	684.0000	.0336745
685.0000	.0337251	686.0000	.0337756	687.0000	.0338262	688.0000	.0338768	689.0000	.0339274
690.0000	.0339780	691.0000	.0340286	692.0000	.0340791	693.0000	.0341297	694.0000	.0341803
695.0000	.0342309	696.0000	.0342815	697.0000	.0343321	698.0000	.0343826	699.0000	.0344332
700.0000	.0344838	701.0000	.0345344	702.0000	.0345850	703.0000	.0346355	704.0000	.0346861
705.0000	.0347367	706.0000	.0347873	707.0000	.0348379	708.0000	.0348885	709.0000	.0349390
710.0000	.0349896	711.0000	.0350402	712.0000	.0350908	713.0000	.0351414	714.0000	.0351919
715.0000	.0352425	716.0000	.0352931	717.0000	.0353437	718.0000	.0353943	719.0000	.0354449
720.0000	.0354954	721.0000	.0355460	722.0000	.0355966	723.0000	.0356472	724.0000	.0356978
725.0000	.0357483	726.0000	.0357989	727.0000	.0358495	728.0000	.0359001	729.0000	.0359507
730.0000	.0360013	731.0000	.0360518	732.0000	.0361024	733.0000	.0361530	734.0000	.0362036
735.0000	.0362542	736.0000	.0363047	737.0000	.0363553	738.0000	.0364059	739.0000	.0364565
740.0000	.0365071	741.0000	.0365577	742.0000	.0366082	743.0000	.0366588	744.0000	.0367094
745.0000	.0367600	746.0000	.0368106	747.0000	.0368611	748.0000	.0369117	749.0000	.0369623
750.0000	.0370129	751.0000	.0370635	752.0000	.0371141	753.0000	.0371646	754.0000	.0372152
755.0000	.0372658	756.0000	.0373164	757.0000	.0373670	758.0000	.0374175	759.0000	.0374681
760.0000	.0375187	761.0000	.0375693	762.0000	.0376199	763.0000	.0376705	764.0000	.0377210
765.0000	.0377716	766.0000	.0378222	767.0000	.0378728	768.0000	.0379234	769.0000	.0379739
770.0000	.0380245	771.0000	.0380751	772.0000	.0381257	773.0000	.0381763	774.0000	.0382269
775.0000	.0382774	776.0000	.0383280	777.0000	.0383786	778.0000	.0384292	779.0000	.0384798
780.0000	.0385303	781.0000	.0385809	782.0000	.0386315	783.0000	.0386821	784.0000	.0387327
785.0000	.0387833	786.0000	.0388338	787.0000	.0388844	788.0000	.0389350	789.0000	.0389856
790.0000	.0390362	791.0000	.0390867	792.0000	.0391373	793.0000	.0391879	794.0000	.0392385
795.0000	.0392891	796.0000	.0393397	797.0000	.0393902	798.0000	.0394408	799.0000	.0394914

TEMPERATURE	20.80								
550.0000	.0267286	551.0000	.0267789	552.0000	.0268292	553.0000	.0268795	554.0000	.0269298
555.0000	.0269800	556.0000	.0270303	557.0000	.0270806	558.0000	.0271309	559.0000	.0271812
560.0000	.0272315	561.0000	.0272818	562.0000	.0273321	563.0000	.0273823	564.0000	.0274326
565.0000	.0274829	566.0000	.0275332	567.0000	.0275835	568.0000	.0276338	569.0000	.0276841
570.0000	.0277344	571.0000	.0277846	572.0000	.0278349	573.0000	.0278852	574.0000	.0279355
575.0000	.0279858	576.0000	.0280361	577.0000	.0280864	578.0000	.0281367	579.0000	.0281869
580.0000	.0282372	581.0000	.0282875	582.0000	.0283378	583.0000	.0283881	584.0000	.0284384
585.0000	.0284887	586.0000	.0285390	587.0000	.0285892	588.0000	.0286395	589.0000	.0286898
590.0000	.0287401	591.0000	.0287904	592.0000	.0288407	593.0000	.0288910	594.0000	.0289413
595.0000	.0289915	596.0000	.0290418	597.0000	.0290921	598.0000	.0291424	599.0000	.0291927
600.0000	.0292430	601.0000	.0292933	602.0000	.0293436	603.0000	.0293938	604.0000	.0294441
605.0000	.0294944	606.0000	.0295447	607.0000	.0295950	608.0000	.0296453	609.0000	.0296956
610.0000	.0297459	611.0000	.0297961	612.0000	.0298464	613.0000	.0298967	614.0000	.0299470
615.0000	.0299973	616.0000	.0300476	617.0000	.0300979	618.0000	.0301482	619.0000	.0301984
620.0000	.0302487	621.0000	.0302990	622.0000	.0303493	623.0000	.0303996	624.0000	.0304499
625.0000	.0305002	626.0000	.0305505	627.0000	.0306007	628.0000	.0306510	629.0000	.0307013
630.0000	.0307516	631.0000	.0308019	632.0000	.0308522	633.0000	.0309025	634.0000	.0309528
635.0000	.0310030	636.0000	.0310533	637.0000	.0311036	638.0000	.0311539	639.0000	.0312042
640.0000	.0312545	641.0000	.0313048	642.0000	.0313551	643.0000	.0314053	644.0000	.0314556
645.0000	.0315059	646.0000	.0315562	647.0000	.0316065	648.0000	.0316568	649.0000	.0317071
650.0000	.0317574	651.0000	.0318076	652.0000	.0318579	653.0000	.0319082	654.0000	.0319585
655.0000	.0320088	656.0000	.0320591	657.0000	.0321094	658.0000	.0321597	659.0000	.0322099
660.0000	.0322602	661.0000	.0323105	662.0000	.0323608	663.0000	.0324111	664.0000	.0324614
665.0000	.0325117	666.0000	.0325620	667.0000	.0326122	668.0000	.0326625	669.0000	.0327128
670.0000	.0327631	671.0000	.0328134	672.0000	.0328637	673.0000	.0329140	674.0000	.0329643
675.0000	.0330145	676.0000	.0330648	677.0000	.0331151	678.0000	.0331654	679.0000	.0332157
680.0000	.0332660	681.0000	.0333163	682.0000	.0333666	683.0000	.0334168	684.0000	.0334671
685.0000	.0335174	686.0000	.0335677	687.0000	.0336180	688.0000	.0336683	689.0000	.0337186
690.0000	.0337689	691.0000	.0338191	692.0000	.0338694	693.0000	.0339197	694.0000	.0339700
695.0000	.0340203	696.0000	.0340706	697.0000	.0341209	698.0000	.0341712	699.0000	.0342214
700.0000	.0342717	701.0000	.0343220	702.0000	.0343723	703.0000	.0344226	704.0000	.0344729
705.0000	.0345232	706.0000	.0345735	707.0000	.0346237	708.0000	.0346740	709.0000	.0347243
710.0000	.0347746	711.0000	.0348249	712.0000	.0348752	713.0000	.0349255	714.0000	.0349758
715.0000	.0350260	716.0000	.0350763	717.0000	.0351266	718.0000	.0351769	719.0000	.0352272
720.0000	.0352775	721.0000	.0353278	722.0000	.0353781	723.0000	.0354283	724.0000	.0354786
725.0000	.0355289	726.0000	.0355792	727.0000	.0356295	728.0000	.0356798	729.0000	.0357301
730.0000	.0357804	731.0000	.0358306	732.0000	.0358809	733.0000	.0359312	734.0000	.0359815
735.0000	.0360318	736.0000	.0360821	737.0000	.0361324	738.0000	.0361827	739.0000	.0362329
740.0000	.0362832	741.0000	.0363335	742.0000	.0363838	743.0000	.0364341	744.0000	.0364844
745.0000	.0365347	746.0000	.0365850	747.0000	.0366352	748.0000	.0366855	749.0000	.0367358
750.0000	.0367861	751.0000	.0368364	752.0000	.0368867	753.0000	.0369370	754.0000	.0369873
755.0000	.0370375	756.0000	.0370878	757.0000	.0371381	758.0000	.0371884	759.0000	.0372387
760.0000	.0372890	761.0000	.0373393	762.0000	.0373896	763.0000	.0374398	764.0000	.0374901
765.0000	.0375404	766.0							

TABLE 3—Continued

TEMPERATURE	21.00								
550.0000	.0265607	551.0000	.0266107	552.0000	.0266607	553.0000	.0267107	554.0000	.0267607
555.0000	.0268107	556.0000	.0268606	557.0000	.0269106	558.0000	.0269606	559.0000	.0270106
560.0000	.0270606	561.0000	.0271106	562.0000	.0271606	563.0000	.0272106	564.0000	.0272606
565.0000	.0273106	566.0000	.0273606	567.0000	.0274106	568.0000	.0274606	569.0000	.0275106
570.0000	.0275606	571.0000	.0276105	572.0000	.0276605	573.0000	.0277105	574.0000	.0277605
575.0000	.0278105	576.0000	.0278605	577.0000	.0279105	578.0000	.0279605	579.0000	.0280105
580.0000	.0280605	581.0000	.0281105	582.0000	.0281605	583.0000	.0282105	584.0000	.0282605
585.0000	.0283105	586.0000	.0283604	587.0000	.0284104	588.0000	.0284604	589.0000	.0285104
590.0000	.0285604	591.0000	.0286104	592.0000	.0286604	593.0000	.0287104	594.0000	.0287604
595.0000	.0288104	596.0000	.0288604	597.0000	.0289104	598.0000	.0289604	599.0000	.0290104
600.0000	.0290603	601.0000	.0291103	602.0000	.0291603	603.0000	.0292103	604.0000	.0292603
605.0000	.0293103	606.0000	.0293603	607.0000	.0294103	608.0000	.0294603	609.0000	.0295103
610.0000	.0295603	611.0000	.0296103	612.0000	.0296603	613.0000	.0297103	614.0000	.0297603
615.0000	.0298102	616.0000	.0298602	617.0000	.0299102	618.0000	.0299602	619.0000	.0300102
620.0000	.0300602	621.0000	.0301102	622.0000	.0301602	623.0000	.0302102	624.0000	.0302602
625.0000	.0303102	626.0000	.0303602	627.0000	.0304102	628.0000	.0304602	629.0000	.0305102
630.0000	.0305601	631.0000	.0306101	632.0000	.0306601	633.0000	.0307101	634.0000	.0307601
635.0000	.0308101	636.0000	.0308601	637.0000	.0309101	638.0000	.0309601	639.0000	.0310101
640.0000	.0310601	641.0000	.0311101	642.0000	.0311601	643.0000	.0312101	644.0000	.0312601
645.0000	.0313100	646.0000	.0313600	647.0000	.0314100	648.0000	.0314600	649.0000	.0315100
650.0000	.0315600	651.0000	.0316100	652.0000	.0316600	653.0000	.0317100	654.0000	.0317600
655.0000	.0318100	656.0000	.0318600	657.0000	.0319100	658.0000	.0319600	659.0000	.0320099
660.0000	.0320599	661.0000	.0321099	662.0000	.0321599	663.0000	.0322099	664.0000	.0322599
665.0000	.0323099	666.0000	.0323599	667.0000	.0324099	668.0000	.0324599	669.0000	.0325099
670.0000	.0325599	671.0000	.0326099	672.0000	.0326599	673.0000	.0327099	674.0000	.0327598
675.0000	.0328098	676.0000	.0328598	677.0000	.0329098	678.0000	.0329598	679.0000	.0330098
680.0000	.0330598	681.0000	.0331098	682.0000	.0331598	683.0000	.0332098	684.0000	.0332598
685.0000	.0333098	686.0000	.0333598	687.0000	.0334098	688.0000	.0334598	689.0000	.0335097
690.0000	.0335597	691.0000	.0336097	692.0000	.0336597	693.0000	.0337097	694.0000	.0337597
695.0000	.0338097	696.0000	.0338597	697.0000	.0339097	698.0000	.0339597	699.0000	.0340097
700.0000	.0340597	701.0000	.0341097	702.0000	.0341597	703.0000	.0342096	704.0000	.0342596
705.0000	.0343096	706.0000	.0343596	707.0000	.0344096	708.0000	.0344596	709.0000	.0345096
710.0000	.0345596	711.0000	.0346096	712.0000	.0346596	713.0000	.0347096	714.0000	.0347596
715.0000	.0348096	716.0000	.0348596	717.0000	.0349096	718.0000	.0349596	719.0000	.0350095
720.0000	.0350595	721.0000	.0351095	722.0000	.0351595	723.0000	.0352095	724.0000	.0352595
725.0000	.0353095	726.0000	.0353595	727.0000	.0354095	728.0000	.0354595	729.0000	.0355095
730.0000	.0355595	731.0000	.0356095	732.0000	.0356595	733.0000	.0357094	734.0000	.0357594
735.0000	.0358094	736.0000	.0358594	737.0000	.0359094	738.0000	.0359594	739.0000	.0360094
740.0000	.0360594	741.0000	.0361094	742.0000	.0361594	743.0000	.0362094	744.0000	.0362594
745.0000	.0363094	746.0000	.0363594	747.0000	.0364093	748.0000	.0364593	749.0000	.0365093
750.0000	.0365593	751.0000	.0366093	752.0000	.0366593	753.0000	.0367093	754.0000	.0367593
755.0000	.0368093	756.0000	.0368593	757.0000	.0369093	758.0000	.0369593	759.0000	.0370093
760.0000	.0370593	761.0000	.0371093	762.0000	.0371592	763.0000	.0372092	764.0000	.0372592
765.0000	.0373092	766.0000	.0373592	767.0000	.0374092	768.0000	.0374592	769.0000	.0375092
770.0000	.0375592	771.0000	.0376092	772.0000	.0376592	773.0000	.0377092	774.0000	.0377592
775.0000	.0378092	776.0000	.0378592	777.0000	.0379091	778.0000	.0379591	779.0000	.0380091
780.0000	.0380591	781.0000	.0381091	782.0000	.0381591	783.0000	.0382091	784.0000	.0382591
785.0000	.0383091	786.0000	.0383591	787.0000	.0384091	788.0000	.0384591	789.0000	.0385091
790.0000	.0385591	791.0000	.0386091	792.0000	.0386590	793.0000	.0387090	794.0000	.0387590
795.0000	.0388090	796.0000	.0388590	797.0000	.0389090	798.0000	.0389590	799.0000	.0390090

TEMPERATURE		21.20							
550.0000	.0263928	551.0000	.0264425	552.0000	.0264922	553.0000	.0265419	554.0000	.0265916
555.0000	.0266413	556.0000	.0266910	557.0000	.0267407	558.0000	.0267904	559.0000	.0268401
560.0000	.0268898	561.0000	.0269395	562.0000	.0269892	563.0000	.0270389	564.0000	.0270886
565.0000	.0271383	566.0000	.0271880	567.0000	.0272377	568.0000	.0272874	569.0000	.0273371
570.0000	.0273868	571.0000	.0274365	572.0000	.0274862	573.0000	.0275359	574.0000	.0275856
575.0000	.0276353	576.0000	.0276850	577.0000	.0277347	578.0000	.0277844	579.0000	.0278341
580.0000	.0278838	581.0000	.0279335	582.0000	.0279832	583.0000	.0280329	584.0000	.0280826
585.0000	.0281323	586.0000	.0281820	587.0000	.0282317	588.0000	.0282814	589.0000	.0283311
590.0000	.0283808	591.0000	.0284305	592.0000	.0284802	593.0000	.0285299	594.0000	.0285796
595.0000	.0286293	596.0000	.0286790	597.0000	.0287287	598.0000	.0287784	599.0000	.0288281
600.0000	.0288778	601.0000	.0289275	602.0000	.0289772	603.0000	.0290269	604.0000	.0290766
605.0000	.0291263	606.0000	.0291760	607.0000	.0292257	608.0000	.0292754	609.0000	.0293251
610.0000	.0293748	611.0000	.0294245	612.0000	.0294742	613.0000	.0295238	614.0000	.0295735
615.0000	.0296232	616.0000	.0296729	617.0000	.0297226	618.0000	.0297723	619.0000	.0298220
620.0000	.0298717	621.0000	.0299214	622.0000	.0299711	623.0000	.0300208	624.0000	.0300705
625.0000	.0301202	626.0000	.0301699	627.0000	.0302196	628.0000	.0302693	629.0000	.0303190
630.0000	.0303687	631.0000	.0304184	632.0000	.0304681	633.0000	.0305178	634.0000	.0305675
635.0000	.0306172	636.0000	.0306669	637.0000	.0307166	638.0000	.0307663	639.0000	.0308160
640.0000	.0308657	641.0000	.0309154	642.0000	.0309651	643.0000	.0310148	644.0000	.0310645
645.0000	.0311142	646.0000	.0311639	647.0000	.0312136	648.0000	.0312633	649.0000	.0313130
650.0000	.0313627	651.0000	.0314124	652.0000	.0314621	653.0000	.0315118	654.0000	.0315615
655.0000	.0316112	656.0000	.0316609	657.0000	.0317106	658.0000	.0317603	659.0000	.0318100
660.0000	.0318597	661.0000	.0319094	662.0000	.0319591	663.0000	.0320088	664.0000	.0320585
665.0000	.0321082	666.0000	.0321579	667.0000	.0322076	668.0000	.0322573	669.0000	.0323070
670.0000	.0323567	671.0000	.0324064	672.0000	.0324561	673.0000	.0325058	674.0000	.0325555
675.0000	.0326052	676.0000	.0326549	677.0000	.0327046	678.0000	.0327543	679.0000	.0328040
680.0000	.0328537	681.0000	.0329034	682.0000	.0329531	683.0000	.0330028	684.0000	.0330525
685.0000	.0331022	686.0000	.0331519	687.0000	.0332016	688.0000	.0332513	689.0000	.0333010
690.0000	.0333507	691.0000	.0334004	692.0000	.0334501	693.0000	.0334998	694.0000	.0335495
695.0000	.0335992	696.0000	.0336489	697.0000	.0336986	698.0000	.0337483	699.0000	.0337980
700.0000	.0338477	701.0000	.0338974	702.0000	.0339470	703.0000	.0339967	704.0000	.0340464
705.0000	.0340961	706.0000	.0341458	707.0000	.0341955	708.0000	.0342452	709.0000	.0342949
710.0000	.0343446	711.0000	.0343943	712.0000	.0344440	713.0000	.0344937	714.0000	.0345434
715.0000	.0345931	716.0000	.0346428	717.0000	.0346925	718.0000	.0347422	719.0000	.0347919
720.0000	.0348416	721.0000	.0348913	722.0000	.0349410	723.0000	.0349907	724.0000	.0350404
725.0000	.0350901	726.0000	.0351398	727.0000	.0351895	728.0000	.0352392	729.0000	.0352889
730.0000	.0353386	731.0000	.0353883	732.0000	.0354380	733.0000	.0354877	734.0000	.0355374
735.0000	.0355871	736.0000	.0356368	737.0000	.0356865	738.0000	.0357362	739.0000	.0357859
740.0000	.0358356	741.0000	.0358853	742.0000	.0359350	743.0000	.0359847	744.0000	.0360344
745.0000	.0360841	746.0000	.0361338	747.0000	.0361835	748.0000	.0362332	749.0000	.0362829
750.0000	.0363326	751.0000	.0363823	752.0000	.0364320	753.0000	.0364817	754.0000	.0365314
755.0000	.0365811	756.0000	.0366308	757.0000	.0366805	758.0000	.0367302	759.0000	.0367799
760.0000	.0368296	761.0000	.0368793	762.0000	.0369290	763.0000	.0369787	764.0000	.0370284
765.0000	.0370781	766.0000	.0371278	767.0000	.0371775	768.0000	.0372272	769.0000	.0372769
770.0000	.0373266	771.0000	.0373763	772.0000	.0374260	773.0000	.0374757	774.0000	.0375254
775.0000	.0375751	776.0000	.0376248	777.0000	.0376745	778.0000	.0377242	779.0000	.0377739
780.0000	.0378236	781.0000	.0378733	782.0000	.0379230	783.0000	.0379727	784.0000	.0380224
785.0000	.0380721	786.0000	.0381218	787.0000	.0381715	788.0000	.0382212	789.0000	.0382709
790.0000	.0383206	791.0000	.0383702	792.0000	.0384199	793.0000	.0384696	794.0000	.0385193
795.0000	.0385690	796.0000	.0386187	797.0000	.0386684	798.0000	.0387181	799.0000	.0387678

TABLE 3—Continued

TEMPERATURE	21.40								
550.0000	.0262249	551.0000	.0262744	552.0000	.0263238	553.0000	.0263732	554.0000	.0264226
555.0000	.0264720	556.0000	.0265214	557.0000	.0265708	558.0000	.0266202	559.0000	.0266696
560.0000	.0267190	561.0000	.0267684	562.0000	.0268178	563.0000	.0268672	564.0000	.0269166
565.0000	.0269660	566.0000	.0270154	567.0000	.0270648	568.0000	.0271142	569.0000	.0271636
570.0000	.0272130	571.0000	.0272624	572.0000	.0273118	573.0000	.0273613	574.0000	.0274107
575.0000	.0274601	576.0000	.0275095	577.0000	.0275589	578.0000	.0276083	579.0000	.0276577
580.0000	.0277071	581.0000	.0277565	582.0000	.0278059	583.0000	.0278553	584.0000	.0279047
585.0000	.0279541	586.0000	.0280035	587.0000	.0280529	588.0000	.0281023	589.0000	.0281517
590.0000	.0282011	591.0000	.0282505	592.0000	.0282999	593.0000	.0283493	594.0000	.0283987
595.0000	.0284482	596.0000	.0284976	597.0000	.0285470	598.0000	.0285964	599.0000	.0286458
600.0000	.0286952	601.0000	.0287446	602.0000	.0287940	603.0000	.0288434	604.0000	.0288928
605.0000	.0289422	606.0000	.0289916	607.0000	.0290410	608.0000	.0290904	609.0000	.0291398
610.0000	.0291892	611.0000	.0292386	612.0000	.0292880	613.0000	.0293374	614.0000	.0293868
615.0000	.0294362	616.0000	.0294856	617.0000	.0295351	618.0000	.0295845	619.0000	.0296339
620.0000	.0296833	621.0000	.0297327	622.0000	.0297821	623.0000	.0298315	624.0000	.0298809
625.0000	.0299303	626.0000	.0299797	627.0000	.0300291	628.0000	.0300785	629.0000	.0301279
630.0000	.0301773	631.0000	.0302267	632.0000	.0302761	633.0000	.0303255	634.0000	.0303749
635.0000	.0304243	636.0000	.0304737	637.0000	.0305231	638.0000	.0305725	639.0000	.0306220
640.0000	.0306714	641.0000	.0307208	642.0000	.0307702	643.0000	.0308196	644.0000	.0308690
645.0000	.0309184	646.0000	.0309678	647.0000	.0310172	648.0000	.0310666	649.0000	.0311160
650.0000	.0311654	651.0000	.0312148	652.0000	.0312642	653.0000	.0313136	654.0000	.0313630
655.0000	.0314124	656.0000	.0314618	657.0000	.0315112	658.0000	.0315606	659.0000	.0316100
660.0000	.0316595	661.0000	.0317089	662.0000	.0317583	663.0000	.0318077	664.0000	.0318571
665.0000	.0319065	666.0000	.0319559	667.0000	.0320053	668.0000	.0320547	669.0000	.0321041
670.0000	.0321535	671.0000	.0322029	672.0000	.0322523	673.0000	.0323017	674.0000	.0323511
675.0000	.0324005	676.0000	.0324499	677.0000	.0324993	678.0000	.0325487	679.0000	.0325981
680.0000	.0326475	681.0000	.0326969	682.0000	.0327463	683.0000	.0327957	684.0000	.0328451
685.0000	.0328946	686.0000	.0329440	687.0000	.0329934	688.0000	.0330428	689.0000	.0330922
690.0000	.0331416	691.0000	.0331910	692.0000	.0332404	693.0000	.0332898	694.0000	.0333392
695.0000	.0333886	696.0000	.0334380	697.0000	.0334874	698.0000	.0335368	699.0000	.0335862
700.0000	.0336356	701.0000	.0336850	702.0000	.0337344	703.0000	.0337838	704.0000	.0338332
705.0000	.0338827	706.0000	.0339321	707.0000	.0339815	708.0000	.0340309	709.0000	.0340803
710.0000	.0341297	711.0000	.0341791	712.0000	.0342285	713.0000	.0342779	714.0000	.0343273
715.0000	.0343767	716.0000	.0344261	717.0000	.0344755	718.0000	.0345249	719.0000	.0345743
720.0000	.0346237	721.0000	.0346731	722.0000	.0347225	723.0000	.0347719	724.0000	.0348213
725.0000	.0348707	726.0000	.0349201	727.0000	.0349695	728.0000	.0350189	729.0000	.0350683
730.0000	.0351178	731.0000	.0351672	732.0000	.0352166	733.0000	.0352660	734.0000	.0353154
735.0000	.0353648	736.0000	.0354142	737.0000	.0354636	738.0000	.0355130	739.0000	.0355624
740.0000	.0356118	741.0000	.0356612	742.0000	.0357106	743.0000	.0357600	744.0000	.0358094
745.0000	.0358588	746.0000	.0359082	747.0000	.0359576	748.0000	.0360071	749.0000	.0360565
750.0000	.0361059	751.0000	.0361553	752.0000	.0362047	753.0000	.0362541	754.0000	.0363035
755.0000	.0363529	756.0000	.0364023	757.0000	.0364517	758.0000	.0365011	759.0000	.0365505
760.0000	.0365999	761.0000	.0366493	762.0000	.0366987	763.0000	.0367481	764.0000	.0367975
765.0000	.0368469	766.0000	.0368963	767.0000	.0369457	768.0000	.0369951	769.0000	.0370445
770.0000	.0370940	771.0000	.0371434	772.0000	.0371928	773.0000	.0372422	774.0000	.0372916
775.0000	.0373410	776.0000	.0373904	777.0000	.0374398	778.0000	.0374892	779.0000	.0375386
780.0000	.0375880	781.0000	.0376374	782.0000	.0376868	783.0000	.0377362	784.0000	.0377856
785.0000	.0378350	786.0000	.0378844	787.0000	.0379338	788.0000	.0379832	789.0000	.0380326
790.0000	.0380820	791.0000	.0381314	792.0000	.0381809	793.0000	.0382303	794.0000	.0382797
795.0000	.0383291	796.0000	.0383785	797.0000	.0384279	798.0000	.0384773	799.0000	.0385267

TEMPERATURE	21.60								
550.0000	.0260571	551.0000	.0261062	552.0000	.0261553	553.0000	.0262044	554.0000	.0262535
555.0000	.0263026	556.0000	.0263517	557.0000	.0264008	558.0000	.0264500	559.0000	.0264991
560.0000	.0265482	561.0000	.0265973	562.0000	.0266464	563.0000	.0266955	564.0000	.0267446
565.0000	.0267937	566.0000	.0268428	567.0000	.0268919	568.0000	.0269411	569.0000	.0269902
570.0000	.0270393	571.0000	.0270884	572.0000	.0271375	573.0000	.0271866	574.0000	.0272357
575.0000	.0272848	576.0000	.0273339	577.0000	.0273831	578.0000	.0274322	579.0000	.0274813
580.0000	.0275304	581.0000	.0275795	582.0000	.0276286	583.0000	.0276777	584.0000	.0277268
585.0000	.0277759	586.0000	.0278250	587.0000	.0278742	588.0000	.0279233	589.0000	.0279724
590.0000	.0280215	591.0000	.0280706	592.0000	.0281197	593.0000	.0281688	594.0000	.0282179
595.0000	.0282670	596.0000	.0283161	597.0000	.0283653	598.0000	.0284144	599.0000	.0284635
600.0000	.0285126	601.0000	.0285617	602.0000	.0286108	603.0000	.0286599	604.0000	.0287090
605.0000	.0287581	606.0000	.0288073	607.0000	.0288564	608.0000	.0289055	609.0000	.0289546
610.0000	.0290037	611.0000	.0290528	612.0000	.0291019	613.0000	.0291510	614.0000	.0292001
615.0000	.0292492	616.0000	.0292984	617.0000	.0293475	618.0000	.0293966	619.0000	.0294457
620.0000	.0294948	621.0000	.0295439	622.0000	.0295930	623.0000	.0296421	624.0000	.0296912
625.0000	.0297403	626.0000	.0297895	627.0000	.0298386	628.0000	.0298877	629.0000	.0299368
630.0000	.0299859	631.0000	.0300350	632.0000	.0300841	633.0000	.0301332	634.0000	.0301823
635.0000	.0302314	636.0000	.0302806	637.0000	.0303297	638.0000	.0303788	639.0000	.0304279
640.0000	.0304770	641.0000	.0305261	642.0000	.0305752	643.0000	.0306243	644.0000	.0306734
645.0000	.0307226	646.0000	.0307717	647.0000	.0308208	648.0000	.0308699	649.0000	.0309190
650.0000	.0309681	651.0000	.0310172	652.0000	.0310663	653.0000	.0311154	654.0000	.0311645
655.0000	.0312137	656.0000	.0312628	657.0000	.0313119	658.0000	.0313610	659.0000	.0314101
660.0000	.0314592	661.0000	.0315083	662.0000	.0315574	663.0000	.0316065	664.0000	.0316556
665.0000	.0317048	666.0000	.0317539	667.0000	.0318030	668.0000	.0318521	669.0000	.0319012
670.0000	.0319503	671.0000	.0319994	672.0000	.0320485	673.0000	.0320976	674.0000	.0321467
675.0000	.0321959	676.0000	.0322450	677.0000	.0322941	678.0000	.0323432	679.0000	.0323923
680.0000	.0324414	681.0000	.0324905	682.0000	.0325396	683.0000	.0325887	684.0000	.0326378
685.0000	.0326870	686.0000	.0327361	687.0000	.0327852	688.0000	.0328343	689.0000	.0328834
690.0000	.0329325	691.0000	.0329816	692.0000	.0330307	693.0000	.0330798	694.0000	.0331289
695.0000	.0331781	696.0000	.0332272	697.0000	.0332763	698.0000	.0333254	699.0000	.0333745
700.0000	.0334236	701.0000	.0334727	702.0000	.0335218	703.0000	.0335709	704.0000	.0336200
705.0000	.0336692	706.0000	.0337183	707.0000	.0337674	708.0000	.0338165	709.0000	.0338656
710.0000	.0339147	711.0000	.0339638	712.0000	.0340129	713.0000	.0340621	714.0000	.0341112
715.0000	.0341603	716.0000	.0342094	717.0000	.0342585	718.0000	.0343076	719.0000	.0343567
720.0000	.0344058	721.0000	.0344549	722.0000	.0345040	723.0000	.0345532	724.0000	.0346023
725.0000	.0346514	726.0000	.0347005	727.0000	.0347496	728.0000	.0347987	729.0000	.0348478
730.0000	.0348969	731.0000	.0349460	732.0000	.0349951	733.0000	.0350443	734.0000	.0350934
735.0000	.0351425	736.0000	.0351916	737.0000	.0352407	738.0000	.0352898	739.0000	.0353389
740.0000	.0353880	741.0000	.0354371	742.0000	.0354862	743.0000	.0355354	744.0000	.0355845
745.0000	.0356336	746.0000	.0356827	747.0000	.0357318	748.0000	.0357809	749.0000	.0358300
750.0000	.0358791	751.0000	.0359282	752.0000	.0359774	753.0000	.0360265	754.0000	.0360756
755.0000	.0361247	756.0000	.0361738	757.0000	.0362229	758.0000	.0362720	759.0000	.0363211
760.0000	.0363702	761.0000	.0364193	762.0000	.0364684	763.0000	.0365176	764.0000	.0365667
765.0000	.0366158	766.							

TABLE 3—Continued

TEMPERATURE 21.80									
550.0000	.0258893	551.0000	.0259381	552.0000	.0259869	553.0000	.0260357	554.0000	.0260845
555.0000	.0261333	556.0000	.0261821	557.0000	.0262310	558.0000	.0262798	559.0000	.0263286
560.0000	.0263774	561.0000	.0264262	562.0000	.0264750	563.0000	.0265239	564.0000	.0265727
565.0000	.0266215	566.0000	.0266703	567.0000	.0267191	568.0000	.0267679	569.0000	.0268168
570.0000	.0268656	571.0000	.0269144	572.0000	.0269632	573.0000	.0270120	574.0000	.0270608
575.0000	.0271097	576.0000	.0271585	577.0000	.0272073	578.0000	.0272561	579.0000	.0273049
580.0000	.0273537	581.0000	.0274025	582.0000	.0274514	583.0000	.0275002	584.0000	.0275490
585.0000	.0275978	586.0000	.0276466	587.0000	.0276954	588.0000	.0277443	589.0000	.0277931
590.0000	.0278419	591.0000	.0278907	592.0000	.0279395	593.0000	.0279883	594.0000	.0280372
595.0000	.0280860	596.0000	.0281348	597.0000	.0281836	598.0000	.0282324	599.0000	.0282812
600.0000	.0283301	601.0000	.0283789	602.0000	.0284277	603.0000	.0284765	604.0000	.0285253
605.0000	.0285741	606.0000	.0286229	607.0000	.0286718	608.0000	.0287206	609.0000	.0287694
610.0000	.0288182	611.0000	.0288670	612.0000	.0289158	613.0000	.0289647	614.0000	.0290135
615.0000	.0290623	616.0000	.0291111	617.0000	.0291599	618.0000	.0292087	619.0000	.0292576
620.0000	.0293064	621.0000	.0293552	622.0000	.0294040	623.0000	.0294528	624.0000	.0295016
625.0000	.0295505	626.0000	.0295993	627.0000	.0296481	628.0000	.0296969	629.0000	.0297457
630.0000	.0297945	631.0000	.0298433	632.0000	.0298922	633.0000	.0299410	634.0000	.0299898
635.0000	.0300386	636.0000	.0300874	637.0000	.0301362	638.0000	.0301851	639.0000	.0302339
640.0000	.0302827	641.0000	.0303315	642.0000	.0303803	643.0000	.0304291	644.0000	.0304780
645.0000	.0305268	646.0000	.0305756	647.0000	.0306244	648.0000	.0306732	649.0000	.0307220
650.0000	.0307709	651.0000	.0308197	652.0000	.0308685	653.0000	.0309173	654.0000	.0309661
655.0000	.0310149	656.0000	.0310638	657.0000	.0311126	658.0000	.0311614	659.0000	.0312102
660.0000	.0312590	661.0000	.0313078	662.0000	.0313566	663.0000	.0314055	664.0000	.0314543
665.0000	.0315031	666.0000	.0315519	667.0000	.0316007	668.0000	.0316495	669.0000	.0316984
670.0000	.0317472	671.0000	.0317960	672.0000	.0318448	673.0000	.0318936	674.0000	.0319424
675.0000	.0319913	676.0000	.0320401	677.0000	.0320889	678.0000	.0321377	679.0000	.0321865
680.0000	.0322353	681.0000	.0322842	682.0000	.0323330	683.0000	.0323818	684.0000	.0324306
685.0000	.0324794	686.0000	.0325282	687.0000	.0325770	688.0000	.0326259	689.0000	.0326747
690.0000	.0327235	691.0000	.0327723	692.0000	.0328211	693.0000	.0328699	694.0000	.0329188
695.0000	.0329676	696.0000	.0330164	697.0000	.0330652	698.0000	.0331140	699.0000	.0331628
700.0000	.0332117	701.0000	.0332605	702.0000	.0333093	703.0000	.0333581	704.0000	.0334069
705.0000	.0334557	706.0000	.0335046	707.0000	.0335534	708.0000	.0336022	709.0000	.0336510
710.0000	.0336998	711.0000	.0337486	712.0000	.0337974	713.0000	.0338463	714.0000	.0338951
715.0000	.0339439	716.0000	.0339927	717.0000	.0340415	718.0000	.0340903	719.0000	.0341392
720.0000	.0341880	721.0000	.0342368	722.0000	.0342856	723.0000	.0343344	724.0000	.0343832
725.0000	.0344321	726.0000	.0344809	727.0000	.0345297	728.0000	.0345785	729.0000	.0346273
730.0000	.0346761	731.0000	.0347250	732.0000	.0347738	733.0000	.0348226	734.0000	.0348714
735.0000	.0349202	736.0000	.0349690	737.0000	.0350178	738.0000	.0350667	739.0000	.0351155
740.0000	.0351643	741.0000	.0352131	742.0000	.0352619	743.0000	.0353107	744.0000	.0353596
745.0000	.0354084	746.0000	.0354572	747.0000	.0355060	748.0000	.0355548	749.0000	.0356036
750.0000	.0356525	751.0000	.0357013	752.0000	.0357501	753.0000	.0357989	754.0000	.0358477
755.0000	.0358965	756.0000	.0359454	757.0000	.0359942	758.0000	.0360430	759.0000	.0360918
760.0000	.0361406	761.0000	.0361894	762.0000	.0362382	763.0000	.0362871	764.0000	.0363359
765.0000	.0363847	766.0000	.0364335	767.0000	.0364823	768.0000	.0365311	769.0000	.0365800
770.0000	.0366288	771.0000	.0366776	772.0000	.0367264	773.0000	.0367752	774.0000	.0368240
775.0000	.0368729	776.0000	.0369217	777.0000	.0369705	778.0000	.0370193	779.0000	.0370681
780.0000	.0371169	781.0000	.0371658	782.0000	.0372146	783.0000	.0372634	784.0000	.0373122
785.0000	.0373610	786.0000	.0374098	787.0000	.0374586	788.0000	.0375075	789.0000	.0375563
790.0000	.0376051	791.0000	.0376539	792.0000	.0377027	793.0000	.0377515	794.0000	.0378004
795.0000	.0378492	796.0000	.0378980	797.0000	.0379468	798.0000	.0379956	799.0000	.0380444

TEMPERATURE 22.00									
550.0000	.0257215	551.0000	.0257700	552.0000	.0258185	553.0000	.0258670	554.0000	.0259156
555.0000	.0259641	556.0000	.0260126	557.0000	.0260611	558.0000	.0261097	559.0000	.0261582
560.0000	.0262067	561.0000	.0262552	562.0000	.0263037	563.0000	.0263523	564.0000	.0264008
565.0000	.0264493	566.0000	.0264978	567.0000	.0265464	568.0000	.0265949	569.0000	.0266434
570.0000	.0266919	571.0000	.0267404	572.0000	.0267890	573.0000	.0268375	574.0000	.0268860
575.0000	.0269345	576.0000	.0269830	577.0000	.0270316	578.0000	.0270801	579.0000	.0271286
580.0000	.0271771	581.0000	.0272257	582.0000	.0272742	583.0000	.0273227	584.0000	.0273712
585.0000	.0274197	586.0000	.0274683	587.0000	.0275168	588.0000	.0275653	589.0000	.0276138
590.0000	.0276624	591.0000	.0277109	592.0000	.0277594	593.0000	.0278079	594.0000	.0278564
595.0000	.0279050	596.0000	.0279535	597.0000	.0280020	598.0000	.0280505	599.0000	.0280990
600.0000	.0281476	601.0000	.0281961	602.0000	.0282446	603.0000	.0282931	604.0000	.0283417
605.0000	.0283902	606.0000	.0284387	607.0000	.0284872	608.0000	.0285357	609.0000	.0285843
610.0000	.0286328	611.0000	.0286813	612.0000	.0287298	613.0000	.0287784	614.0000	.0288269
615.0000	.0288754	616.0000	.0289239	617.0000	.0289724	618.0000	.0290210	619.0000	.0290695
620.0000	.0291180	621.0000	.0291665	622.0000	.0292151	623.0000	.0292636	624.0000	.0293121
625.0000	.0293606	626.0000	.0294091	627.0000	.0294577	628.0000	.0295062	629.0000	.0295547
630.0000	.0296032	631.0000	.0296517	632.0000	.0297003	633.0000	.0297488	634.0000	.0297973
635.0000	.0298458	636.0000	.0298944	637.0000	.0299429	638.0000	.0299914	639.0000	.0300399
640.0000	.0300884	641.0000	.0301370	642.0000	.0301855	643.0000	.0302340	644.0000	.0302825
645.0000	.0303311	646.0000	.0303796	647.0000	.0304281	648.0000	.0304766	649.0000	.0305251
650.0000	.0305737	651.0000	.0306222	652.0000	.0306707	653.0000	.0307192	654.0000	.0307677
655.0000	.0308163	656.0000	.0308648	657.0000	.0309133	658.0000	.0309618	659.0000	.0310104
660.0000	.0310589	661.0000	.0311074	662.0000	.0311559	663.0000	.0312044	664.0000	.0312530
665.0000	.0313015	666.0000	.0313500	667.0000	.0313985	6			

TABLE 3—Continued

TEMPERATURE 22.20									
550.0000	.0255537	551.0000	.0256019	552.0000	.0256502	553.0000	.0256984	554.0000	.0257466
555.0000	.0257949	556.0000	.0258431	557.0000	.0258913	558.0000	.0259395	559.0000	.0259878
560.0000	.0260360	561.0000	.0260842	562.0000	.0261325	563.0000	.0261807	564.0000	.0262289
565.0000	.0262771	566.0000	.0263254	567.0000	.0263736	568.0000	.0264218	569.0000	.0264700
570.0000	.0265183	571.0000	.0265665	572.0000	.0266147	573.0000	.0266630	574.0000	.0267112
575.0000	.0267594	576.0000	.0268076	577.0000	.0268559	578.0000	.0269041	579.0000	.0269523
580.0000	.0270005	581.0000	.0270488	582.0000	.0270970	583.0000	.0271452	584.0000	.0271935
585.0000	.0272417	586.0000	.0272899	587.0000	.0273381	588.0000	.0273864	589.0000	.0274346
590.0000	.0274828	591.0000	.0275310	592.0000	.0275793	593.0000	.0276275	594.0000	.0276757
595.0000	.0277240	596.0000	.0277722	597.0000	.0278204	598.0000	.0278686	599.0000	.0279169
600.0000	.0279651	601.0000	.0280133	602.0000	.0280616	603.0000	.0281098	604.0000	.0281580
605.0000	.0282062	606.0000	.0282545	607.0000	.0283027	608.0000	.0283509	609.0000	.0283991
610.0000	.0284474	611.0000	.0284956	612.0000	.0285438	613.0000	.0285921	614.0000	.0286403
615.0000	.0286885	616.0000	.0287367	617.0000	.0287850	618.0000	.0288332	619.0000	.0288814
620.0000	.0289296	621.0000	.0289779	622.0000	.0290261	623.0000	.0290743	624.0000	.0291226
625.0000	.0291708	626.0000	.0292190	627.0000	.0292672	628.0000	.0293155	629.0000	.0293637
630.0000	.0294119	631.0000	.0294602	632.0000	.0295084	633.0000	.0295566	634.0000	.0296048
635.0000	.0296531	636.0000	.0297013	637.0000	.0297495	638.0000	.0297977	639.0000	.0298460
640.0000	.0298942	641.0000	.0299424	642.0000	.0299907	643.0000	.0300389	644.0000	.0300871
645.0000	.0301353	646.0000	.0301836	647.0000	.0302318	648.0000	.0302800	649.0000	.0303282
650.0000	.0303765	651.0000	.0304247	652.0000	.0304729	653.0000	.0305212	654.0000	.0305694
655.0000	.0306176	656.0000	.0306658	657.0000	.0307141	658.0000	.0307623	659.0000	.0308105
660.0000	.0308588	661.0000	.0309070	662.0000	.0309552	663.0000	.0310034	664.0000	.0310517
665.0000	.0310999	666.0000	.0311481	667.0000	.0311963	668.0000	.0312446	669.0000	.0312928
670.0000	.0313410	671.0000	.0313893	672.0000	.0314375	673.0000	.0314857	674.0000	.0315339
675.0000	.0315822	676.0000	.0316304	677.0000	.0316786	678.0000	.0317268	679.0000	.0317751
680.0000	.0318233	681.0000	.0318715	682.0000	.0319198	683.0000	.0319680	684.0000	.0320162
685.0000	.0320644	686.0000	.0321127	687.0000	.0321609	688.0000	.0322091	689.0000	.0322573
690.0000	.0323056	691.0000	.0323538	692.0000	.0324020	693.0000	.0324503	694.0000	.0324985
695.0000	.0325467	696.0000	.0325949	697.0000	.0326432	698.0000	.0326914	699.0000	.0327396
700.0000	.0327879	701.0000	.0328361	702.0000	.0328843	703.0000	.0329325	704.0000	.0329808
705.0000	.0330290	706.0000	.0330772	707.0000	.0331254	708.0000	.0331737	709.0000	.0332219
710.0000	.0332701	711.0000	.0333184	712.0000	.0333666	713.0000	.0334148	714.0000	.0334630
715.0000	.0335113	716.0000	.0335595	717.0000	.0336077	718.0000	.0336559	719.0000	.0337042
720.0000	.0337524	721.0000	.0338006	722.0000	.0338489	723.0000	.0338971	724.0000	.0339453
725.0000	.0339935	726.0000	.0340418	727.0000	.0340900	728.0000	.0341382	729.0000	.0341865
730.0000	.0342347	731.0000	.0342829	732.0000	.0343311	733.0000	.0343794	734.0000	.0344276
735.0000	.0344758	736.0000	.0345240	737.0000	.0345723	738.0000	.0346205	739.0000	.0346687
740.0000	.0347170	741.0000	.0347652	742.0000	.0348134	743.0000	.0348616	744.0000	.0349099
745.0000	.0349581	746.0000	.0350063	747.0000	.0350545	748.0000	.0351028	749.0000	.0351510
750.0000	.0351992	751.0000	.0352475	752.0000	.0352957	753.0000	.0353439	754.0000	.0353921
755.0000	.0354404	756.0000	.0354886	757.0000	.0355368	758.0000	.0355851	759.0000	.0356333
760.0000	.0356815	761.0000	.0357297	762.0000	.0357780	763.0000	.0358262	764.0000	.0358744
765.0000	.0359226	766.0000	.0359709	767.0000	.0360191	768.0000	.0360673	769.0000	.0361156
770.0000	.0361638	771.0000	.0362120	772.0000	.0362602	773.0000	.0363085	774.0000	.0363567
775.0000	.0364049	776.0000	.0364531	777.0000	.0365014	778.0000	.0365496	779.0000	.0365978
780.0000	.0366461	781.0000	.0366943	782.0000	.0367425	783.0000	.0367907	784.0000	.0368390
785.0000	.0368872	786.0000	.0369354	787.0000	.0369836	788.0000	.0370319	789.0000	.0370801
790.0000	.0371283	791.0000	.0371766	792.0000	.0372248	793.0000	.0372730	794.0000	.0373212
795.0000	.0373695	796.0000	.0374177	797.0000	.0374659	798.0000	.0375142	799.0000	.0375624

TEMPERATURE 22.40									
550.0000	.0253860	551.0000	.0254339	552.0000	.0254818	553.0000	.0255298	554.0000	.0255777
555.0000	.0256256	556.0000	.0256736	557.0000	.0257215	558.0000	.0257694	559.0000	.0258174
560.0000	.0258653	561.0000	.0259132	562.0000	.0259612	563.0000	.0260091	564.0000	.0260570
565.0000	.0261050	566.0000	.0261529	567.0000	.0262008	568.0000	.0262488	569.0000	.0262967
570.0000	.0263446	571.0000	.0263926	572.0000	.0264405	573.0000	.0264884	574.0000	.0265364
575.0000	.0265843	576.0000	.0266322	577.0000	.0266802	578.0000	.0267281	579.0000	.0267760
580.0000	.0268240	581.0000	.0268719	582.0000	.0269198	583.0000	.0269678	584.0000	.0270157
585.0000	.0270636	586.0000	.0271116	587.0000	.0271595	588.0000	.0272074	589.0000	.0272554
590.0000	.0273033	591.0000	.0273512	592.0000	.0273992	593.0000	.0274471	594.0000	.0274950
595.0000	.0275430	596.0000	.0275909	597.0000	.0276388	598.0000	.0276868	599.0000	.0277347
600.0000	.0277826	601.0000	.0278306	602.0000	.0278785	603.0000	.0279264	604.0000	.0279744
605.0000	.0280223	606.0000	.0280702	607.0000	.0281182	608.0000	.0281661	609.0000	.0282140
610.0000	.0282620	611.0000	.0283099	612.0000	.0283578	613.0000	.0284058	614.0000	.0284537
615.0000	.0285016	616.0000	.0285496	617.0000	.0285975	618.0000	.0286454	619.0000	.0286934
620.0000	.0287413	621.0000	.0287892	622.0000	.0288372	623.0000	.0288851	624.0000	.0289330
625.0000	.0289810	626.0000	.0290289	627.0000	.0290768	628.0000	.0291248	629.0000	.0291727
630.0000	.0292206	631.0000	.0292686	632.0000	.0293165	633.0000	.0293644	634.0000	.0294124
635.0000	.0294603	636.0000	.0295082	637.0000	.0295562	638.0000	.0296041	639.0000	.0296520
640.0000	.0297000	641.0000	.0297479	642.0000	.0297958	643.0000	.0298438	644.0000	.0298917
645.0000	.0299396	646.0000	.0299876	647.0000	.0300355	648.0000	.0300834	649.0000	.0301314
650.0000	.0301793	651.0000	.0302272	652.0000	.0302752	653.0000	.0303231	654.0000	.0303710
655.0000	.0304190	656.0000	.0304669	657.0000	.0305148	658.0000	.0305628	659.0000	.0306107
660.0000	.0306586	661.0000	.0307066	662.0000	.0307545	663.0000	.0308024	664.0000	.0308504
665.0000	.0308983	666.0000	.0309462	667.0000	.0309942	668.0000	.0310421	669.0000	.0310900
670.0000	.0311380	671.0000	.0311859	672.0000	.0312338	673.0000	.0312818	674.0000	.0313297
675.0000	.0313776	676.0000	.0314256	677.0000	.0314735	678.0000	.0315214	679.0000	.0315694
680.0000	.0316173	681.0000	.0316652	682.0000	.0317132	683.0000	.0317611	684.0000	.0318090
685.0000	.0318570	686.0000	.0319049	687.0000	.0319528	688.0000	.0320008	689.0000	.0320487
690.0000	.0320966	691.0000	.0321446	692.0000	.0321925	693.0000	.0322404	694.0000	.0322884
695.0000	.0323363	696.0000	.0323842	697.0000	.0324322	698.0000	.0324801	699.0000	.0325280
700.0000	.0325760	701.0000	.0326239	702.0000	.0326718	703.0000	.0327198	704.0000	.0327677
705.0000	.0328156	706.0000	.0328636	707.0000	.0329115	708.0000	.0329594	709.0000	.0330074
710.0000	.0330553	711.0000	.0331032	712.0000	.0331512	713.0000	.0331991	714.0000	.0332470
715.0000	.0332950	716.0000	.0333429	717.0000	.0333908	718.0000	.0334388	719.0000	.0334867
720.0000	.0335346	721.0000	.0335826	722.0000	.0336305	723.0000	.0336784	724.0000	.0337264
725.0000	.0337743	726.0000	.0338222	727.0000	.0338702	728.0000	.0339181	729.0000	.0339660
730.0000	.0340140	731.0000	.0340619	732.0000	.0341098	733.0000	.0341578	734.0000	.0342057
735.0000	.0342536	736.0000	.0343016	737.0000	.0343495	738.0000	.0343974	739.0000	.0344454
740.0000	.0344933	741.0000	.0345412	742.0000	.0345892	743.0000	.0346371	744.0000	.0346850
745.0000	.0347330	746.0000	.0347809	747.0000	.0348288	748.0000	.0348768	749.0000	.0349247
750.0000	.0349726	751.0000	.0350206	752.0000	.0350685	753.0000	.0351164	754.0000	.0351644
755.0000	.0352123	756.0000	.0352602	757.0000	.0353082	758.0000	.0353561	759.0000	.0354040
760.0000	.0354520	761.0000	.0354999	762.00					

TABLE 3—Continued

TEMPERATURE 22.60									
550.0000	.0252182	551.0000	.0252659	552.0000	.0253135	553.0000	.0253611	554.0000	.0254088
555.0000	.0254564	556.0000	.0255041	557.0000	.0255517	558.0000	.0255993	559.0000	.0256470
560.0000	.0256946	561.0000	.0257423	562.0000	.0257899	563.0000	.0258375	564.0000	.0258852
565.0000	.0259328	566.0000	.0259804	567.0000	.0260281	568.0000	.0260757	569.0000	.0261234
570.0000	.0261710	571.0000	.0262186	572.0000	.0262663	573.0000	.0263139	574.0000	.0263616
575.0000	.0264092	576.0000	.0264568	577.0000	.0265045	578.0000	.0265521	579.0000	.0265998
580.0000	.0266474	581.0000	.0266950	582.0000	.0267427	583.0000	.0267903	584.0000	.0268380
585.0000	.0268856	586.0000	.0269332	587.0000	.0269809	588.0000	.0270285	589.0000	.0270762
590.0000	.0271238	591.0000	.0271714	592.0000	.0272191	593.0000	.0272667	594.0000	.0273143
595.0000	.0273620	596.0000	.0274096	597.0000	.0274573	598.0000	.0275049	599.0000	.0275525
600.0000	.0276002	601.0000	.0276478	602.0000	.0276955	603.0000	.0277431	604.0000	.0277907
605.0000	.0278384	606.0000	.0278860	607.0000	.0279337	608.0000	.0279813	609.0000	.0280289
610.0000	.0280766	611.0000	.0281242	612.0000	.0281719	613.0000	.0282195	614.0000	.0282671
615.0000	.0283148	616.0000	.0283624	617.0000	.0284100	618.0000	.0284577	619.0000	.0285053
620.0000	.0285530	621.0000	.0286006	622.0000	.0286482	623.0000	.0286959	624.0000	.0287435
625.0000	.0287912	626.0000	.0288388	627.0000	.0288864	628.0000	.0289341	629.0000	.0289817
630.0000	.0290294	631.0000	.0290770	632.0000	.0291246	633.0000	.0291723	634.0000	.0292199
635.0000	.0292676	636.0000	.0293152	637.0000	.0293628	638.0000	.0294105	639.0000	.0294581
640.0000	.0295057	641.0000	.0295534	642.0000	.0296010	643.0000	.0296487	644.0000	.0296963
645.0000	.0297439	646.0000	.0297916	647.0000	.0298392	648.0000	.0298869	649.0000	.0299345
650.0000	.0299821	651.0000	.0300298	652.0000	.0300774	653.0000	.0301251	654.0000	.0301727
655.0000	.0302203	656.0000	.0302680	657.0000	.0303156	658.0000	.0303633	659.0000	.0304109
660.0000	.0304585	661.0000	.0305062	662.0000	.0305538	663.0000	.0306014	664.0000	.0306491
665.0000	.0306967	666.0000	.0307444	667.0000	.0307920	668.0000	.0308396	669.0000	.0308873
670.0000	.0309349	671.0000	.0309826	672.0000	.0310302	673.0000	.0310778	674.0000	.0311255
675.0000	.0311731	676.0000	.0312208	677.0000	.0312684	678.0000	.0313160	679.0000	.0313637
680.0000	.0314113	681.0000	.0314590	682.0000	.0315066	683.0000	.0315542	684.0000	.0316019
685.0000	.0316495	686.0000	.0316971	687.0000	.0317448	688.0000	.0317924	689.0000	.0318401
690.0000	.0318877	691.0000	.0319353	692.0000	.0319830	693.0000	.0320306	694.0000	.0320783
695.0000	.0321259	696.0000	.0321735	697.0000	.0322212	698.0000	.0322688	699.0000	.0323165
700.0000	.0323641	701.0000	.0324117	702.0000	.0324594	703.0000	.0325070	704.0000	.0325547
705.0000	.0326023	706.0000	.0326499	707.0000	.0326976	708.0000	.0327452	709.0000	.0327928
710.0000	.0328405	711.0000	.0328881	712.0000	.0329358	713.0000	.0329834	714.0000	.0330310
715.0000	.0330787	716.0000	.0331263	717.0000	.0331740	718.0000	.0332216	719.0000	.0332692
720.0000	.0333169	721.0000	.0333645	722.0000	.0334122	723.0000	.0334598	724.0000	.0335074
725.0000	.0335551	726.0000	.0336027	727.0000	.0336504	728.0000	.0336980	729.0000	.0337456
730.0000	.0337933	731.0000	.0338409	732.0000	.0338885	733.0000	.0339362	734.0000	.0339838
735.0000	.0340315	736.0000	.0340791	737.0000	.0341267	738.0000	.0341744	739.0000	.0342220
740.0000	.0342697	741.0000	.0343173	742.0000	.0343649	743.0000	.0344126	744.0000	.0344602
745.0000	.0345079	746.0000	.0345555	747.0000	.0346031	748.0000	.0346508	749.0000	.0346984
750.0000	.0347461	751.0000	.0347937	752.0000	.0348413	753.0000	.0348890	754.0000	.0349366
755.0000	.0349843	756.0000	.0350319	757.0000	.0350795	758.0000	.0351272	759.0000	.0351748
760.0000	.0352224	761.0000	.0352701	762.0000	.0353177	763.0000	.0353654	764.0000	.0354130
765.0000	.0354606	766.0000	.0355083	767.0000	.0355559	768.0000	.0356036	769.0000	.0356512
770.0000	.0356988	771.0000	.0357465	772.0000	.0357941	773.0000	.0358418	774.0000	.0358894
775.0000	.0359370	776.0000	.0359847	777.0000	.0360323	778.0000	.0360800	779.0000	.0361276
780.0000	.0361752	781.0000	.0362229	782.0000	.0362705	783.0000	.0363181	784.0000	.0363658
785.0000	.0364134	786.0000	.0364611	787.0000	.0365087	788.0000	.0365563	789.0000	.0366040
790.0000	.0366516	791.0000	.0366993	792.0000	.0367469	793.0000	.0367945	794.0000	.0368422
795.0000	.0368898	796.0000	.0369375	797.0000	.0369851	798.0000	.0370327	799.0000	.0370804
TEMPERATURE 22.80									
550.0000	.0250504	551.0000	.0250978	552.0000	.0251451	553.0000	.0251925	554.0000	.0252398
555.0000	.0252872	556.0000	.0253345	557.0000	.0253819	558.0000	.0254292	559.0000	.0254766
560.0000	.0255239	561.0000	.0255712	562.0000	.0256186	563.0000	.0256659	564.0000	.0257133
565.0000	.0257606	566.0000	.0258080	567.0000	.0258553	568.0000	.0259027	569.0000	.0259500
570.0000	.0259973	571.0000	.0260447	572.0000	.0260920	573.0000	.0261394	574.0000	.0261867
575.0000	.0262341	576.0000	.0262814	577.0000	.0263288	578.0000	.0263761	579.0000	.0264235
580.0000	.0264708	581.0000	.0265181	582.0000	.0265655	583.0000	.0266128	584.0000	.0266602
585.0000	.0267075	586.0000	.0267549	587.0000	.0268022	588.0000	.0268496	589.0000	.0268969
590.0000	.0269442	591.0000	.0269916	592.0000	.0270389	593.0000	.0270863	594.0000	.0271336
595.0000	.0271810	596.0000	.0272283	597.0000	.0272757	598.0000	.0273230	599.0000	.0273704
600.0000	.0274177	601.0000	.0274650	602.0000	.0275124	603.0000	.0275597	604.0000	.0276071
605.0000	.0276544	606.0000	.0277018	607.0000	.0277491	608.0000	.0277965	609.0000	.0278438
610.0000	.0278911	611.0000	.0279385	612.0000	.0279858	613.0000	.0280332	614.0000	.0280805
615.0000	.0281279	616.0000	.0281752	617.0000	.0282226	618.0000	.0282699	619.0000	.0283173
620.0000	.0283646	621.0000	.0284119	622.0000	.0284593	623.0000	.0285066	624.0000	.0285540
625.0000	.0286013	626.0000	.0286487	627.0000	.0286960	628.0000	.0287434	629.0000	.0287907
630.0000	.0288380	631.0000	.0288854	632.0000	.0289327	633.0000	.0289801	634.0000	.0290274
635.0000	.0290748	636.0000	.0291221	637.0000	.0291695	638.0000	.0292168	639.0000	.0292642
640.0000	.0293115	641.0000	.0293588	642.0000	.0294062	643.0000	.0294535	644.0000	.0295009
645.0000	.0295482	646.0000	.0295956	647.0000	.0296429	648.0000	.0296903	649.0000	.0297376
650.0000	.0297849	651.0000	.0298323	652.0000	.0298796	653.0000	.0299270	654.0000	.0299743
655.0000	.0300217	656.0000	.0300690	657.0000	.0301164	658.0000	.0301637	659.0000	.0302111
660.0000	.0302584	661.0000	.0303057	662.0000	.0303531	663.0000	.0304004	664.0000	.0304478
665.0000	.0304951	666.0000	.0305425	667.0000	.0305898	668.0			

TABLE 3—Continued

TEMPERATURE	23.00								
550.0000	.0248830	551.0000	.0249300	552.0000	.0249771	553.0000	.0250241	554.0000	.0250712
555.0000	.0251182	556.0000	.0251653	557.0000	.0252123	558.0000	.0252594	559.0000	.0253064
560.0000	.0253535	561.0000	.0254005	562.0000	.0254476	563.0000	.0254946	564.0000	.0255417
565.0000	.0255887	566.0000	.0256358	567.0000	.0256828	568.0000	.0257299	569.0000	.0257769
570.0000	.0258240	571.0000	.0258710	572.0000	.0259181	573.0000	.0259651	574.0000	.0260122
575.0000	.0260592	576.0000	.0261063	577.0000	.0261533	578.0000	.0262004	579.0000	.0262474
580.0000	.0262945	581.0000	.0263415	582.0000	.0263886	583.0000	.0264356	584.0000	.0264827
585.0000	.0265298	586.0000	.0265768	587.0000	.0266239	588.0000	.0266709	589.0000	.0267180
590.0000	.0267650	591.0000	.0268121	592.0000	.0268591	593.0000	.0269062	594.0000	.0269532
595.0000	.0270003	596.0000	.0270473	597.0000	.0270944	598.0000	.0271414	599.0000	.0271885
600.0000	.0272355	601.0000	.0272826	602.0000	.0273296	603.0000	.0273767	604.0000	.0274237
605.0000	.0274708	606.0000	.0275178	607.0000	.0275649	608.0000	.0276119	609.0000	.0276590
610.0000	.0277060	611.0000	.0277531	612.0000	.0278001	613.0000	.0278472	614.0000	.0278942
615.0000	.0279413	616.0000	.0279883	617.0000	.0280354	618.0000	.0280824	619.0000	.0281295
620.0000	.0281765	621.0000	.0282236	622.0000	.0282706	623.0000	.0283177	624.0000	.0283647
625.0000	.0284118	626.0000	.0284588	627.0000	.0285059	628.0000	.0285529	629.0000	.0286000
630.0000	.0286470	631.0000	.0286941	632.0000	.0287411	633.0000	.0287882	634.0000	.0288352
635.0000	.0288823	636.0000	.0289293	637.0000	.0289764	638.0000	.0290234	639.0000	.0290705
640.0000	.0291175	641.0000	.0291646	642.0000	.0292116	643.0000	.0292587	644.0000	.0293058
645.0000	.0293528	646.0000	.0293999	647.0000	.0294469	648.0000	.0294940	649.0000	.0295410
650.0000	.0295881	651.0000	.0296351	652.0000	.0296822	653.0000	.0297292	654.0000	.0297763
655.0000	.0298233	656.0000	.0298704	657.0000	.0299174	658.0000	.0299645	659.0000	.0300115
660.0000	.0300586	661.0000	.0301056	662.0000	.0301527	663.0000	.0301997	664.0000	.0302468
665.0000	.0302938	666.0000	.0303409	667.0000	.0303879	668.0000	.0304350	669.0000	.0304820
670.0000	.0305291	671.0000	.0305761	672.0000	.0306232	673.0000	.0306702	674.0000	.0307173
675.0000	.0307643	676.0000	.0308114	677.0000	.0308584	678.0000	.0309055	679.0000	.0309525
680.0000	.0309996	681.0000	.0310466	682.0000	.0310937	683.0000	.0311407	684.0000	.0311878
685.0000	.0312348	686.0000	.0312819	687.0000	.0313289	688.0000	.0313760	689.0000	.0314230
690.0000	.0314701	691.0000	.0315171	692.0000	.0315642	693.0000	.0316112	694.0000	.0316583
695.0000	.0317053	696.0000	.0317524	697.0000	.0317994	698.0000	.0318465	699.0000	.0318935
700.0000	.0319406	701.0000	.0319876	702.0000	.0320347	703.0000	.0320818	704.0000	.0321288
705.0000	.0321759	706.0000	.0322229	707.0000	.0322700	708.0000	.0323170	709.0000	.0323641
710.0000	.0324111	711.0000	.0324582	712.0000	.0325052	713.0000	.0325523	714.0000	.0325993
715.0000	.0326464	716.0000	.0326934	717.0000	.0327405	718.0000	.0327875	719.0000	.0328346
720.0000	.0328816	721.0000	.0329287	722.0000	.0329757	723.0000	.0330228	724.0000	.0330698
725.0000	.0331169	726.0000	.0331639	727.0000	.0332110	728.0000	.0332580	729.0000	.0333051
730.0000	.0333521	731.0000	.0333992	732.0000	.0334462	733.0000	.0334933	734.0000	.0335403
735.0000	.0335874	736.0000	.0336344	737.0000	.0336815	738.0000	.0337285	739.0000	.0337756
740.0000	.0338226	741.0000	.0338697	742.0000	.0339167	743.0000	.0339638	744.0000	.0340108
745.0000	.0340579	746.0000	.0341049	747.0000	.0341520	748.0000	.0341990	749.0000	.0342461
750.0000	.0342931	751.0000	.0343402	752.0000	.0343872	753.0000	.0344343	754.0000	.0344813
755.0000	.0345284	756.0000	.0345754	757.0000	.0346225	758.0000	.0346695	759.0000	.0347166
760.0000	.0347636	761.0000	.0348107	762.0000	.0348577	763.0000	.0349048	764.0000	.0349519
765.0000	.0349989	766.0000	.0350460	767.0000	.0350930	768.0000	.0351401	769.0000	.0351871
770.0000	.0352342	771.0000	.0352812	772.0000	.0353283	773.0000	.0353753	774.0000	.0354224
775.0000	.0354694	776.0000	.0355165	777.0000	.0355635	778.0000	.0356106	779.0000	.0356576
780.0000	.0357047	781.0000	.0357517	782.0000	.0357988	783.0000	.0358458	784.0000	.0358929
785.0000	.0359399	786.0000	.0359870	787.0000	.0360340	788.0000	.0360811	789.0000	.0361281
790.0000	.0361752	791.0000	.0362222	792.0000	.0362693	793.0000	.0363163	794.0000	.0363634
795.0000	.0364104	796.0000	.0364575	797.0000	.0365045	798.0000	.0365516	799.0000	.0365986

TEMPERATURE	23.20								
550.0000	.0247154	551.0000	.0247621	552.0000	.0248089	553.0000	.0248556	554.0000	.0249024
555.0000	.0249492	556.0000	.0249959	557.0000	.0250427	558.0000	.0250894	559.0000	.0251362
560.0000	.0251829	561.0000	.0252297	562.0000	.0252765	563.0000	.0253232	564.0000	.0253700
565.0000	.0254167	566.0000	.0254635	567.0000	.0255102	568.0000	.0255570	569.0000	.0256038
570.0000	.0256505	571.0000	.0256973	572.0000	.0257440	573.0000	.0257908	574.0000	.0258375
575.0000	.0258843	576.0000	.0259310	577.0000	.0259778	578.0000	.0260246	579.0000	.0260713
580.0000	.0261181	581.0000	.0261648	582.0000	.0262116	583.0000	.0262583	584.0000	.0263051
585.0000	.0263519	586.0000	.0263986	587.0000	.0264454	588.0000	.0264921	589.0000	.0265389
590.0000	.0265856	591.0000	.0266322	592.0000	.0266792	593.0000	.0267259	594.0000	.0267727
595.0000	.0268194	596.0000	.0268662	597.0000	.0269129	598.0000	.0269597	599.0000	.0270065
600.0000	.0270532	601.0000	.0271000	602.0000	.0271467	603.0000	.0271935	604.0000	.0272402
605.0000	.0272870	606.0000	.0273337	607.0000	.0273805	608.0000	.0274273	609.0000	.0274740
610.0000	.0275208	611.0000	.0275675	612.0000	.0276143	613.0000	.0276610	614.0000	.0277078
615.0000	.0277546	616.0000	.0278013	617.0000	.0278481	618.0000	.0278948	619.0000	.0279416
620.0000	.0279883	621.0000	.0280351	622.0000	.0280819	623.0000	.0281286	624.0000	.0281754
625.0000	.0282221	626.0000	.0282689	627.0000	.0283156	628.0000	.0283624	629.0000	.0284092
630.0000	.0284559	631.0000	.0285027	632.0000	.0285494	633.0000	.0285962	634.0000	.0286429
635.0000	.0286897	636.0000	.0287364	637.0000	.0287832	638.0000	.0288300	639.0000	.0288767
640.0000	.0289235	641.0000	.0289702	642.0000	.0290170	643.0000	.0290637	644.0000	.0291105
645.0000	.0291573	646.0000	.0292040	647.0000	.0292508	648.0000	.0292975	649.0000	.0293443
650.0000	.0293910	651.0000	.0294378	652.0000	.0294846	653.0000	.0295313	654.0000	.0295781
655.0000	.0296248	656.0000	.0296716	657.0000	.0297183	658.0000	.0297651	659.0000	.0298119
660.0000	.0298586	661.0000	.0299054	662.0000	.0299521	663.0000	.0299989	664.0000	.0300456
665.0000	.0300924	666.0000	.0301392	667.0000	.0301859	668.0000	.0302327	669.0000	.0302794
670.0000	.0303262	671.0000	.0303729	672.0000	.0304197	673.0000	.0304664	674.0000	.0305132
675.0000	.0305600	676.0000	.0306067	677.0000	.0306535	678.0000	.0307002	679.0000	.0307470
680.0000	.0307937	681.0000	.0308405	682.0000	.0308873	683.0000	.0309340	684.0000	.0309808
685.0000	.0310275	686.0000	.0310743	687.0000	.0311210	688.0000	.0311678	689.0000	.0312146
690.0000	.0312613	691.0000	.0313081	692.0000	.0313548	693.0000	.0314016	694.0000	.0314483
695.0000	.0314951	696.0000	.0315419	697.0000	.0315886	698.0000	.0316354	699.0000	.0316821
700.0000	.0317289	701.0000	.0317756	702.0000	.0318224	703.0000	.0318691	704.0000	.0319159
705.0000	.0319627	706.0000	.0320094	707.0000	.0320562	708.0000	.0321029	709.0000	.0321497
710.0000	.0321964	711.0000	.0322432	712.0000	.0322900	713.0000	.0323367	714.0000	.0323835
715.0000	.0324302	716.0000	.0324770	717.0000	.0325237	718.0000	.0325705	719.0000	.0326173
720.0000	.0326640	721.0000	.0327108	722.0000	.0327575	723.0000	.0328043	724.0000	.0328510
725.0000	.0328978	726.0000	.0329446	727.0000	.0329913	728.0000	.0330381	729.0000	.0330848
730.0000	.0331316	731.0000	.0331783	732.0000	.0332251	733.0000	.0332719	734.0000	.0333186
735.0000	.0333654	736.0000	.0334121	737.0000	.0334589	738.0000	.0335056	739.0000	.0335524
740.0000	.0335991	741.0000	.0336459	742.0000	.0336927	743.0000	.0337394	744.0000	.0337862
745.0000	.0338329	746.0000	.0338797	747.0000	.0339264	748.0000	.0339732	749.0000	.0340200
750.0000	.0340667	751.0000	.0341135	752.0000	.0341602	753.0000	.0342070	754.0000	.0342537
755.0000	.0343005	756.0000	.0343473	757.0000	.0343940	758.0000	.0344408	759.0000	.0344875
760.0000	.0345343	761.0000	.0345810	762.0000	.0346278	763.0000	.0346746	764.0000	.0347213
765.0000	.0347681	766.							

TABLE 3—Continued

TEMPERATURE 23.40									
550.0000	.0245478	551.0000	.0245943	552.0000	.0246407	553.0000	.0246872	554.0000	.0247336
555.0000	.0247801	556.0000	.0248266	557.0000	.0248730	558.0000	.0249195	559.0000	.0249660
560.0000	.0250124	561.0000	.0250589	562.0000	.0251053	563.0000	.0251518	564.0000	.0251983
565.0000	.0252447	566.0000	.0252912	567.0000	.0253377	568.0000	.0253841	569.0000	.0254306
570.0000	.0254770	571.0000	.0255235	572.0000	.0255700	573.0000	.0256164	574.0000	.0256629
575.0000	.0257094	576.0000	.0257558	577.0000	.0258023	578.0000	.0258487	579.0000	.0258952
580.0000	.0259417	581.0000	.0259881	582.0000	.0260346	583.0000	.0260811	584.0000	.0261275
585.0000	.0261740	586.0000	.0262204	587.0000	.0262669	588.0000	.0263134	589.0000	.0263598
590.0000	.0264063	591.0000	.0264528	592.0000	.0264992	593.0000	.0265457	594.0000	.0265921
595.0000	.0266386	596.0000	.0266851	597.0000	.0267315	598.0000	.0267780	599.0000	.0268245
600.0000	.0268709	601.0000	.0269174	602.0000	.0269638	603.0000	.0270103	604.0000	.0270568
605.0000	.0271032	606.0000	.0271497	607.0000	.0271962	608.0000	.0272426	609.0000	.0272891
610.0000	.0273356	611.0000	.0273820	612.0000	.0274285	613.0000	.0274749	614.0000	.0275214
615.0000	.0275679	616.0000	.0276143	617.0000	.0276608	618.0000	.0277073	619.0000	.0277537
620.0000	.0278002	621.0000	.0278466	622.0000	.0278931	623.0000	.0279396	624.0000	.0279860
625.0000	.0280325	626.0000	.0280790	627.0000	.0281254	628.0000	.0281719	629.0000	.0282183
630.0000	.0282648	631.0000	.0283113	632.0000	.0283577	633.0000	.0284042	634.0000	.0284507
635.0000	.0284971	636.0000	.0285436	637.0000	.0285900	638.0000	.0286365	639.0000	.0286830
640.0000	.0287294	641.0000	.0287759	642.0000	.0288224	643.0000	.0288688	644.0000	.0289153
645.0000	.0289617	646.0000	.0290082	647.0000	.0290547	648.0000	.0291011	649.0000	.0291476
650.0000	.0291941	651.0000	.0292405	652.0000	.0292870	653.0000	.0293334	654.0000	.0293799
655.0000	.0294264	656.0000	.0294728	657.0000	.0295193	658.0000	.0295658	659.0000	.0296122
660.0000	.0296587	661.0000	.0297051	662.0000	.0297516	663.0000	.0297981	664.0000	.0298445
665.0000	.0298910	666.0000	.0299375	667.0000	.0299839	668.0000	.0300304	669.0000	.0300768
670.0000	.0301233	671.0000	.0301698	672.0000	.0302162	673.0000	.0302627	674.0000	.0303092
675.0000	.0303556	676.0000	.0304021	677.0000	.0304485	678.0000	.0304950	679.0000	.0305415
680.0000	.0305879	681.0000	.0306344	682.0000	.0306809	683.0000	.0307273	684.0000	.0307738
685.0000	.0308202	686.0000	.0308667	687.0000	.0309132	688.0000	.0309596	689.0000	.0310061
690.0000	.0310526	691.0000	.0310990	692.0000	.0311455	693.0000	.0311919	694.0000	.0312384
695.0000	.0312849	696.0000	.0313313	697.0000	.0313778	698.0000	.0314243	699.0000	.0314707
700.0000	.0315172	701.0000	.0315636	702.0000	.0316101	703.0000	.0316566	704.0000	.0317030
705.0000	.0317495	706.0000	.0317960	707.0000	.0318424	708.0000	.0318889	709.0000	.0319353
710.0000	.0319818	711.0000	.0320283	712.0000	.0320747	713.0000	.0321212	714.0000	.0321677
715.0000	.0322141	716.0000	.0322606	717.0000	.0323070	718.0000	.0323535	719.0000	.0324000
720.0000	.0324464	721.0000	.0324929	722.0000	.0325394	723.0000	.0325858	724.0000	.0326323
725.0000	.0326787	726.0000	.0327252	727.0000	.0327717	728.0000	.0328181	729.0000	.0328646
730.0000	.0329111	731.0000	.0329575	732.0000	.0330040	733.0000	.0330505	734.0000	.0330969
735.0000	.0331434	736.0000	.0331898	737.0000	.0332363	738.0000	.0332828	739.0000	.0333292
740.0000	.0333757	741.0000	.0334222	742.0000	.0334686	743.0000	.0335151	744.0000	.0335615
745.0000	.0336080	746.0000	.0336545	747.0000	.0337009	748.0000	.0337474	749.0000	.0337938
750.0000	.0338403	751.0000	.0338868	752.0000	.0339332	753.0000	.0339797	754.0000	.0340262
755.0000	.0340726	756.0000	.0341191	757.0000	.0341656	758.0000	.0342120	759.0000	.0342585
760.0000	.0343049	761.0000	.0343514	762.0000	.0343979	763.0000	.0344443	764.0000	.0344908
765.0000	.0345373	766.0000	.0345837	767.0000	.0346302	768.0000	.0346766	769.0000	.0347231
770.0000	.0347696	771.0000	.0348160	772.0000	.0348625	773.0000	.0349090	774.0000	.0349554
775.0000	.0350019	776.0000	.0350483	777.0000	.0350948	778.0000	.0351413	779.0000	.0351877
780.0000	.0352342	781.0000	.0352807	782.0000	.0353271	783.0000	.0353736	784.0000	.0354200
785.0000	.0354665	786.0000	.0355130	787.0000	.0355594	788.0000	.0356059	789.0000	.0356524
790.0000	.0356988	791.0000	.0357453	792.0000	.0357917	793.0000	.0358382	794.0000	.0358847
795.0000	.0359311	796.0000	.0359776	797.0000	.0360241	798.0000	.0360705	799.0000	.0361170

TEMPERATURE 23.60									
550.0000	.0244111	551.0000	.0244574	552.0000	.0245036	553.0000	.0245498	554.0000	.0245960
555.0000	.0246423	556.0000	.0246885	557.0000	.0247347	558.0000	.0247810	559.0000	.0248272
560.0000	.0248734	561.0000	.0249196	562.0000	.0249659	563.0000	.0250121	564.0000	.0250583
565.0000	.0251045	566.0000	.0251508	567.0000	.0251970	568.0000	.0252432	569.0000	.0252895
570.0000	.0253357	571.0000	.0253819	572.0000	.0254281	573.0000	.0254744	574.0000	.0255206
575.0000	.0255668	576.0000	.0256130	577.0000	.0256593	578.0000	.0257055	579.0000	.0257517
580.0000	.0257980	581.0000	.0258442	582.0000	.0258904	583.0000	.0259366	584.0000	.0259829
585.0000	.0260291	586.0000	.0260753	587.0000	.0261215	588.0000	.0261678	589.0000	.0262140
590.0000	.0262602	591.0000	.0263064	592.0000	.0263527	593.0000	.0263989	594.0000	.0264451
595.0000	.0264914	596.0000	.0265376	597.0000	.0265838	598.0000	.0266300	599.0000	.0266763
600.0000	.0267225	601.0000	.0267687	602.0000	.0268149	603.0000	.0268612	604.0000	.0269074
605.0000	.0269536	606.0000	.0269999	607.0000	.0270461	608.0000	.0270923	609.0000	.0271385
610.0000	.0271848	611.0000	.0272310	612.0000	.0272772	613.0000	.0273234	614.0000	.0273697
615.0000	.0274159	616.0000	.0274621	617.0000	.0275084	618.0000	.0275546	619.0000	.0276008
620.0000	.0276470	621.0000	.0276933	622.0000	.0277395	623.0000	.0277857	624.0000	.0278319
625.0000	.0278782	626.0000	.0279244	627.0000	.0279706	628.0000	.0280168	629.0000	.0280631
630.0000	.0281093	631.0000	.0281555	632.0000	.0282018	633.0000	.0282480	634.0000	.0282942
635.0000	.0283404	636.0000	.0283867	637.0000	.0284329	638.0000	.0284791	639.0000	.0285253
640.0000	.0285716	641.0000	.0286178	642.0000	.0286640	643.0000	.0287103	644.0000	.0287565
645.0000	.0288027	646.0000	.0288489	647.0000	.0288952	648.0000	.0289414	649.0000	.0289876
650.0000	.0290338	651.0000	.0290800	652.0000	.0291263	653.0000	.0291725	654.0000	.0292187
655.0000	.0292650	656.0000	.0293112	657.0000	.0293574	658.0000	.0294037	659.0000	.0294499
660.0000	.0294961	661.0000	.0295423	662.0000	.0295886	663.0000	.0296348	664.0000	.0296810
665.0000	.0297272	666.0000	.0297735	667.0000	.0298197	6			

TABLE 3—Continued

TEMPERATURE 23.80									
550.0000	.0242745	551.0000	.0243205	552.0000	.0243665	553.0000	.0244125	554.0000	.0244584
555.0000	.0245044	556.0000	.0245504	557.0000	.0245964	558.0000	.0246424	559.0000	.0246884
560.0000	.0247344	561.0000	.0247804	562.0000	.0248264	563.0000	.0248724	564.0000	.0249184
565.0000	.0249644	566.0000	.0250103	567.0000	.0250563	568.0000	.0251023	569.0000	.0251483
570.0000	.0251943	571.0000	.0252403	572.0000	.0252863	573.0000	.0253323	574.0000	.0253783
575.0000	.0254243	576.0000	.0254703	577.0000	.0255162	578.0000	.0255622	579.0000	.0256082
580.0000	.0256542	581.0000	.0257002	582.0000	.0257462	583.0000	.0257922	584.0000	.0258382
585.0000	.0258842	586.0000	.0259302	587.0000	.0259762	588.0000	.0260222	589.0000	.0260681
590.0000	.0261141	591.0000	.0261601	592.0000	.0262061	593.0000	.0262521	594.0000	.0262981
595.0000	.0263441	596.0000	.0263901	597.0000	.0264361	598.0000	.0264821	599.0000	.0265281
600.0000	.0265741	601.0000	.0266200	602.0000	.0266660	603.0000	.0267120	604.0000	.0267580
605.0000	.0268040	606.0000	.0268500	607.0000	.0268960	608.0000	.0269420	609.0000	.0269880
610.0000	.0270340	611.0000	.0270800	612.0000	.0271259	613.0000	.0271719	614.0000	.0272179
615.0000	.0272639	616.0000	.0273099	617.0000	.0273559	618.0000	.0274019	619.0000	.0274479
620.0000	.0274939	621.0000	.0275399	622.0000	.0275859	623.0000	.0276319	624.0000	.0276778
625.0000	.0277238	626.0000	.0277698	627.0000	.0278158	628.0000	.0278618	629.0000	.0279078
630.0000	.0279538	631.0000	.0279998	632.0000	.0280458	633.0000	.0280918	634.0000	.0281378
635.0000	.0281838	636.0000	.0282297	637.0000	.0282757	638.0000	.0283217	639.0000	.0283677
640.0000	.0284137	641.0000	.0284597	642.0000	.0285057	643.0000	.0285517	644.0000	.0285977
645.0000	.0286437	646.0000	.0286897	647.0000	.0287356	648.0000	.0287816	649.0000	.0288276
650.0000	.0288736	651.0000	.0289196	652.0000	.0289656	653.0000	.0290116	654.0000	.0290576
655.0000	.0291036	656.0000	.0291496	657.0000	.0291956	658.0000	.0292416	659.0000	.0292875
660.0000	.0293335	661.0000	.0293795	662.0000	.0294255	663.0000	.0294715	664.0000	.0295175
665.0000	.0295635	666.0000	.0296095	667.0000	.0296555	668.0000	.0297015	669.0000	.0297475
670.0000	.0297935	671.0000	.0298394	672.0000	.0298854	673.0000	.0299314	674.0000	.0299774
675.0000	.0300234	676.0000	.0300694	677.0000	.0301154	678.0000	.0301614	679.0000	.0302074
680.0000	.0302534	681.0000	.0302994	682.0000	.0303454	683.0000	.0303913	684.0000	.0304373
685.0000	.0304833	686.0000	.0305293	687.0000	.0305753	688.0000	.0306213	689.0000	.0306673
690.0000	.0307133	691.0000	.0307593	692.0000	.0308053	693.0000	.0308513	694.0000	.0308972
695.0000	.0309432	696.0000	.0309892	697.0000	.0310352	698.0000	.0310812	699.0000	.0311272
700.0000	.0311732	701.0000	.0312192	702.0000	.0312652	703.0000	.0313112	704.0000	.0313572
705.0000	.0314032	706.0000	.0314491	707.0000	.0314951	708.0000	.0315411	709.0000	.0315871
710.0000	.0316331	711.0000	.0316791	712.0000	.0317251	713.0000	.0317711	714.0000	.0318171
715.0000	.0318631	716.0000	.0319091	717.0000	.0319551	718.0000	.0320010	719.0000	.0320470
720.0000	.0320930	721.0000	.0321390	722.0000	.0321850	723.0000	.0322310	724.0000	.0322770
725.0000	.0323230	726.0000	.0323690	727.0000	.0324150	728.0000	.0324610	729.0000	.0325069
730.0000	.0325529	731.0000	.0325989	732.0000	.0326449	733.0000	.0326909	734.0000	.0327369
735.0000	.0327829	736.0000	.0328289	737.0000	.0328749	738.0000	.0329209	739.0000	.0329669
740.0000	.0330129	741.0000	.0330588	742.0000	.0331048	743.0000	.0331508	744.0000	.0331968
745.0000	.0332428	746.0000	.0332888	747.0000	.0333348	748.0000	.0333808	749.0000	.0334268
750.0000	.0334728	751.0000	.0335188	752.0000	.0335648	753.0000	.0336107	754.0000	.0336567
755.0000	.0337027	756.0000	.0337487	757.0000	.0337947	758.0000	.0338407	759.0000	.0338867
760.0000	.0339327	761.0000	.0339787	762.0000	.0340247	763.0000	.0340707	764.0000	.0341166
765.0000	.0341626	766.0000	.0342086	767.0000	.0342546	768.0000	.0343006	769.0000	.0343466
770.0000	.0343926	771.0000	.0344386	772.0000	.0344846	773.0000	.0345306	774.0000	.0345766
775.0000	.0346226	776.0000	.0346685	777.0000	.0347145	778.0000	.0347605	779.0000	.0348065
780.0000	.0348525	781.0000	.0348985	782.0000	.0349445	783.0000	.0349905	784.0000	.0350365
785.0000	.0350825	786.0000	.0351285	787.0000	.0351745	788.0000	.0352204	789.0000	.0352664
790.0000	.0353124	791.0000	.0353584	792.0000	.0354044	793.0000	.0354504	794.0000	.0354964
795.0000	.0355424	796.0000	.0355884	797.0000	.0356344	798.0000	.0356804	799.0000	.0357264
TEMPERATURE 24.00									
550.0000	.0241070	551.0000	.0241527	552.0000	.0241984	553.0000	.0242441	554.0000	.0242898
555.0000	.0243355	556.0000	.0243812	557.0000	.0244269	558.0000	.0244726	559.0000	.0245183
560.0000	.0245640	561.0000	.0246097	562.0000	.0246554	563.0000	.0247011	564.0000	.0247468
565.0000	.0247925	566.0000	.0248381	567.0000	.0248838	568.0000	.0249295	569.0000	.0249752
570.0000	.0250209	571.0000	.0250666	572.0000	.0251123	573.0000	.0251580	574.0000	.0252037
575.0000	.0252494	576.0000	.0252951	577.0000	.0253408	578.0000	.0253865	579.0000	.0254322
580.0000	.0254779	581.0000	.0255236	582.0000	.0255693	583.0000	.0256150	584.0000	.0256607
585.0000	.0257064	586.0000	.0257521	587.0000	.0257978	588.0000	.0258435	589.0000	.0258892
590.0000	.0259349	591.0000	.0259806	592.0000	.0260263	593.0000	.0260720	594.0000	.0261177
595.0000	.0261634	596.0000	.0262091	597.0000	.0262548	598.0000	.0263005	599.0000	.0263462
600.0000	.0263919	601.0000	.0264376	602.0000	.0264833	603.0000	.0265290	604.0000	.0265747
605.0000	.0266203	606.0000	.0266660	607.0000	.0267117	608.0000	.0267574	609.0000	.0268031
610.0000	.0268488	611.0000	.0268945	612.0000	.0269402	613.0000	.0269859	614.0000	.0270316
615.0000	.0270773	616.0000	.0271230	617.0000	.0271687	618.0000	.0272144	619.0000	.0272601
620.0000	.0273058	621.0000	.0273515	622.0000	.0273972	623.0000	.0274429	624.0000	.0274886
625.0000	.0275343	626.0000	.0275800	627.0000	.0276257	628.0000	.0276714	629.0000	.0277171
630.0000	.0277628	631.0000	.0278085	632.0000	.0278542	633.0000	.0278999	634.0000	.0279456
635.0000	.0279913	636.0000	.0280370	637.0000	.0280827	638.0000	.0281284	639.0000	.0281741
640.0000	.0282198	641.0000	.0282655	642.0000	.0283112	643.0000	.0283568	644.0000	.0284025
645.0000	.0284482	646.0000	.0284939	647.0000	.0285396	648.0000	.0285853	649.0000	.0286310
650.0000	.0286767	651.0000	.0287224	652.0000	.0287681	653.0000	.0288138	654.0000	.0288595
655.0000	.0289052	656.0000	.0289509	657.0000	.0289966	658.0000	.0290423	659.0000	.0290880
660.0000	.0291337	661.0000	.0291794	662.0000	.0292251	663.0000	.0292708	664.0000	.0293165
665.0000</									

TABLE 3—Continued

TEMPERATURE	24.20								
550.0000	.0239395	551.0000	.0239849	552.0000	.0240303	553.0000	.0240757	554.0000	.0241211
555.0000	.0241665	556.0000	.0242119	557.0000	.0242573	558.0000	.0243027	559.0000	.0243481
560.0000	.0243935	561.0000	.0244389	562.0000	.0244843	563.0000	.0245297	564.0000	.0245751
565.0000	.0246205	566.0000	.0246659	567.0000	.0247113	568.0000	.0247567	569.0000	.0248022
570.0000	.0248476	571.0000	.0248930	572.0000	.0249384	573.0000	.0249838	574.0000	.0250292
575.0000	.0250746	576.0000	.0251200	577.0000	.0251654	578.0000	.0252108	579.0000	.0252562
580.0000	.0253016	581.0000	.0253470	582.0000	.0253924	583.0000	.0254378	584.0000	.0254832
585.0000	.0255286	586.0000	.0255740	587.0000	.0256194	588.0000	.0256648	589.0000	.0257102
590.0000	.0257556	591.0000	.0258010	592.0000	.0258464	593.0000	.0258918	594.0000	.0259372
595.0000	.0259826	596.0000	.0260280	597.0000	.0260734	598.0000	.0261188	599.0000	.0261642
600.0000	.0262097	601.0000	.0262551	602.0000	.0263005	603.0000	.0263459	604.0000	.0263913
605.0000	.0264367	606.0000	.0264821	607.0000	.0265275	608.0000	.0265729	609.0000	.0266183
610.0000	.0266637	611.0000	.0267091	612.0000	.0267545	613.0000	.0267999	614.0000	.0268453
615.0000	.0268907	616.0000	.0269361	617.0000	.0269815	618.0000	.0270269	619.0000	.0270723
620.0000	.0271177	621.0000	.0271631	622.0000	.0272085	623.0000	.0272539	624.0000	.0272993
625.0000	.0273447	626.0000	.0273901	627.0000	.0274355	628.0000	.0274810	629.0000	.0275264
630.0000	.0275718	631.0000	.0276172	632.0000	.0276626	633.0000	.0277080	634.0000	.0277534
635.0000	.0277988	636.0000	.0278442	637.0000	.0278896	638.0000	.0279350	639.0000	.0279804
640.0000	.0280258	641.0000	.0280712	642.0000	.0281166	643.0000	.0281620	644.0000	.0282074
645.0000	.0282528	646.0000	.0282982	647.0000	.0283436	648.0000	.0283890	649.0000	.0284344
650.0000	.0284798	651.0000	.0285252	652.0000	.0285706	653.0000	.0286160	654.0000	.0286614
655.0000	.0287068	656.0000	.0287522	657.0000	.0287976	658.0000	.0288430	659.0000	.0288884
660.0000	.0289339	661.0000	.0289793	662.0000	.0290247	663.0000	.0290701	664.0000	.0291155
665.0000	.0291609	666.0000	.0292063	667.0000	.0292517	668.0000	.0292971	669.0000	.0293425
670.0000	.0293879	671.0000	.0294333	672.0000	.0294787	673.0000	.0295241	674.0000	.0295695
675.0000	.0296149	676.0000	.0296603	677.0000	.0297057	678.0000	.0297511	679.0000	.0297965
680.0000	.0298419	681.0000	.0298873	682.0000	.0299327	683.0000	.0299781	684.0000	.0300235
685.0000	.0300689	686.0000	.0301143	687.0000	.0301597	688.0000	.0302051	689.0000	.0302505
690.0000	.0302960	691.0000	.0303414	692.0000	.0303868	693.0000	.0304322	694.0000	.0304776
695.0000	.0305230	696.0000	.0305684	697.0000	.0306138	698.0000	.0306592	699.0000	.0307046
700.0000	.0307500	701.0000	.0307954	702.0000	.0308408	703.0000	.0308862	704.0000	.0309316
705.0000	.0309770	706.0000	.0310224	707.0000	.0310678	708.0000	.0311132	709.0000	.0311586
710.0000	.0312040	711.0000	.0312494	712.0000	.0312948	713.0000	.0313402	714.0000	.0313856
715.0000	.0314310	716.0000	.0314764	717.0000	.0315218	718.0000	.0315672	719.0000	.0316126
720.0000	.0316581	721.0000	.0317035	722.0000	.0317489	723.0000	.0317943	724.0000	.0318397
725.0000	.0318851	726.0000	.0319305	727.0000	.0319759	728.0000	.0320213	729.0000	.0320667
730.0000	.0321121	731.0000	.0321575	732.0000	.0322029	733.0000	.0322483	734.0000	.0322937
735.0000	.0323391	736.0000	.0323845	737.0000	.0324299	738.0000	.0324753	739.0000	.0325207
740.0000	.0325661	741.0000	.0326115	742.0000	.0326569	743.0000	.0327023	744.0000	.0327477
745.0000	.0327931	746.0000	.0328385	747.0000	.0328840	748.0000	.0329294	749.0000	.0329748
750.0000	.0330202	751.0000	.0330656	752.0000	.0331110	753.0000	.0331564	754.0000	.0332018
755.0000	.0332472	756.0000	.0332926	757.0000	.0333380	758.0000	.0333834	759.0000	.0334288
760.0000	.0334742	761.0000	.0335196	762.0000	.0335650	763.0000	.0336104	764.0000	.0336558
765.0000	.0337012	766.0000	.0337466	767.0000	.0337920	768.0000	.0338374	769.0000	.0338828
770.0000	.0339282	771.0000	.0339736	772.0000	.0340190	773.0000	.0340644	774.0000	.0341098
775.0000	.0341552	776.0000	.0342006	777.0000	.0342460	778.0000	.0342914	779.0000	.0343368
780.0000	.0343823	781.0000	.0344277	782.0000	.0344731	783.0000	.0345185	784.0000	.0345639
785.0000	.0346093	786.0000	.0346547	787.0000	.0347001	788.0000	.0347455	789.0000	.0347909
790.0000	.0348363	791.0000	.0348817	792.0000	.0349271	793.0000	.0349725	794.0000	.0350179
795.0000	.0350633	796.0000	.0351087	797.0000	.0351541	798.0000	.0351995	799.0000	.0352449

TEMPERATURE	24.40								
550.0000	.0237720	551.0000	.0238171	552.0000	.0238622	553.0000	.0239073	554.0000	.0239525
555.0000	.0239976	556.0000	.0240427	557.0000	.0240878	558.0000	.0241329	559.0000	.0241780
560.0000	.0242231	561.0000	.0242682	562.0000	.0243133	563.0000	.0243584	564.0000	.0244036
565.0000	.0244487	566.0000	.0244938	567.0000	.0245389	568.0000	.0245840	569.0000	.0246291
570.0000	.0246742	571.0000	.0247193	572.0000	.0247644	573.0000	.0248095	574.0000	.0248546
575.0000	.0248998	576.0000	.0249449	577.0000	.0249900	578.0000	.0250351	579.0000	.0250802
580.0000	.0251253	581.0000	.0251704	582.0000	.0252155	583.0000	.0252606	584.0000	.0253057
585.0000	.0253508	586.0000	.0253960	587.0000	.0254411	588.0000	.0254862	589.0000	.0255313
590.0000	.0255764	591.0000	.0256215	592.0000	.0256666	593.0000	.0257117	594.0000	.0257568
595.0000	.0258019	596.0000	.0258471	597.0000	.0258922	598.0000	.0259373	599.0000	.0259824
600.0000	.0260275	601.0000	.0260726	602.0000	.0261177	603.0000	.0261628	604.0000	.0262079
605.0000	.0262530	606.0000	.0262981	607.0000	.0263433	608.0000	.0263884	609.0000	.0264335
610.0000	.0264786	611.0000	.0265237	612.0000	.0265688	613.0000	.0266139	614.0000	.0266590
615.0000	.0267041	616.0000	.0267492	617.0000	.0267943	618.0000	.0268394	619.0000	.0268845
620.0000	.0269297	621.0000	.0269748	622.0000	.0270199	623.0000	.0270650	624.0000	.0271101
625.0000	.0271552	626.0000	.0272003	627.0000	.0272454	628.0000	.0272905	629.0000	.0273357
630.0000	.0273808	631.0000	.0274259	632.0000	.0274710	633.0000	.0275161	634.0000	.0275612
635.0000	.0276063	636.0000	.0276514	637.0000	.0276965	638.0000	.0277416	639.0000	.0277868
640.0000	.0278319	641.0000	.0278770	642.0000	.0279221	643.0000	.0279672	644.0000	.0280123
645.0000	.0280574	646.0000	.0281025	647.0000	.0281476	648.0000	.0281927	649.0000	.0282378
650.0000	.0282830	651.0000	.0283281	652.0000	.0283732	653.0000	.0284183	654.0000	.0284634
655.0000	.0285085	656.0000	.0285536	657.0000	.0285987	658.0000	.0286438	659.0000	.0286889
660.0000	.0287340	661.0000	.0287791	662.0000	.0288242	663.0000	.0288693	664.0000	.0289144
665.0000	.0289596	666.0000	.0290047	667.0000	.0290498	668.0000	.0290949	669.0000	.0291400
670.0000	.0291851	671.0000	.0292303	672.0000	.0292754	673.0000	.0293205	674.0000	.0293656
675.0000	.0294107	676.0000	.0294558	677.0000	.0295009	678.0000	.0295460	679.0000	.0295911
680.0000	.0296362	681.0000	.0296813	682.0000	.0297265	683.0000	.0297716	684.0000	.0298167
685.0000	.0298618	686.0000	.0299069	687.0000	.0299520	688.0000	.0299971	689.0000	.0300422
690.0000	.0300873	691.0000	.0301324	692.0000	.0301775	693.0000	.0302227	694.0000	.0302678
695.0000	.0303129	696.0000	.0303580	697.0000	.0304031	698.0000	.0304482	699.0000	.0304933
700.0000	.0305384	701.0000	.0305835	702.0000	.0306286	703.0000	.0306737	704.0000	.0307188
705.0000	.0307640	706.0000	.0308091	707.0000	.0308542	708.0000	.0308993	709.0000	.0309444
710.0000	.0309895	711.0000	.0310346	712.0000	.0310797	713.0000	.0311248	714.0000	.0311700
715.0000	.0312151	716.0000	.0312602	717.0000	.0313053	718.0000	.0313504	719.0000	.0313955
720.0000	.0314406	721.0000	.0314857	722.0000	.0315308	723.0000	.0315759	724.0000	.0316210
725.0000	.0316662	726.0000	.0317113	727.0000	.0317564	728.0000	.0318015	729.0000	.0318466
730.0000	.0318917	731.0000	.0319368	732.0000	.0319819	733.0000	.0320270	734.0000	.0320721
735.0000	.0321172	736.0000	.0321623	737.0000	.0322074	738.0000	.0322525	739.0000	.0322976
740.0000	.0323428	741.0000	.0323879	742.0000	.0324330	743.0000	.0324781	744.0000	.0325232
745.0000	.0325683	746.0000	.0326134	747.0000	.0326585	748.0000	.0327036	749.0000	.0327487
750.0000	.0327939	751.0000	.0328390	752.0000	.0328841	753.0000	.0329292	754.0000	.0329743
755.0000	.0330194	756.0000	.0330645	757.0000	.0331096	758.0000	.0331547	759.0000	.0331998
760.0000	.0332450	761.0000	.0332901	762.0000	.0333352	763.0000	.0333803	764.0000	.0334254
765.0000	.0334705	766.							

TABLE 3—Continued

TEMPERATURE	24.60								
550.0000	.0236354	551.0000	.0236803	552.0000	.0237252	553.0000	.0237701	554.0000	.0238149
555.0000	.0238598	556.0000	.0239047	557.0000	.0239496	558.0000	.0239944	559.0000	.0240393
560.0000	.0240842	561.0000	.0241291	562.0000	.0241739	563.0000	.0242188	564.0000	.0242637
565.0000	.0243086	566.0000	.0243534	567.0000	.0243983	568.0000	.0244432	569.0000	.0244881
570.0000	.0245329	571.0000	.0245778	572.0000	.0246227	573.0000	.0246675	574.0000	.0247124
575.0000	.0247573	576.0000	.0248022	577.0000	.0248470	578.0000	.0248919	579.0000	.0249368
580.0000	.0249817	581.0000	.0250265	582.0000	.0250714	583.0000	.0251163	584.0000	.0251612
585.0000	.0252060	586.0000	.0252509	587.0000	.0252958	588.0000	.0253407	589.0000	.0253855
590.0000	.0254304	591.0000	.0254753	592.0000	.0255202	593.0000	.0255650	594.0000	.0256099
595.0000	.0256548	596.0000	.0256996	597.0000	.0257445	598.0000	.0257894	599.0000	.0258343
600.0000	.0258791	601.0000	.0259240	602.0000	.0259689	603.0000	.0260138	604.0000	.0260586
605.0000	.0261035	606.0000	.0261484	607.0000	.0261933	608.0000	.0262381	609.0000	.0262830
610.0000	.0263279	611.0000	.0263728	612.0000	.0264176	613.0000	.0264625	614.0000	.0265074
615.0000	.0265522	616.0000	.0265971	617.0000	.0266420	618.0000	.0266869	619.0000	.0267317
620.0000	.0267766	621.0000	.0268215	622.0000	.0268664	623.0000	.0269112	624.0000	.0269561
625.0000	.0270010	626.0000	.0270459	627.0000	.0270907	628.0000	.0271356	629.0000	.0271805
630.0000	.0272254	631.0000	.0272702	632.0000	.0273151	633.0000	.0273600	634.0000	.0274049
635.0000	.0274497	636.0000	.0274946	637.0000	.0275395	638.0000	.0275843	639.0000	.0276292
640.0000	.0276741	641.0000	.0277190	642.0000	.0277638	643.0000	.0278087	644.0000	.0278536
645.0000	.0278985	646.0000	.0279433	647.0000	.0279882	648.0000	.0280331	649.0000	.0280780
650.0000	.0281228	651.0000	.0281677	652.0000	.0282126	653.0000	.0282575	654.0000	.0283023
655.0000	.0283472	656.0000	.0283921	657.0000	.0284370	658.0000	.0284818	659.0000	.0285267
660.0000	.0285716	661.0000	.0286164	662.0000	.0286613	663.0000	.0287062	664.0000	.0287511
665.0000	.0287459	666.0000	.0287908	667.0000	.0288357	668.0000	.0288806	669.0000	.0289254
670.0000	.0290203	671.0000	.0290652	672.0000	.0291101	673.0000	.0291549	674.0000	.0291998
675.0000	.0292447	676.0000	.0292896	677.0000	.0293344	678.0000	.0293793	679.0000	.0294242
680.0000	.0294690	681.0000	.0295139	682.0000	.0295588	683.0000	.0296037	684.0000	.0296485
685.0000	.0296934	686.0000	.0297383	687.0000	.0297832	688.0000	.0298280	689.0000	.0298729
690.0000	.0299178	691.0000	.0299627	692.0000	.0300075	693.0000	.0300524	694.0000	.0300973
695.0000	.0301422	696.0000	.0301870	697.0000	.0302319	698.0000	.0302768	699.0000	.0303217
700.0000	.0303665	701.0000	.0304114	702.0000	.0304563	703.0000	.0305011	704.0000	.0305460
705.0000	.0305909	706.0000	.0306358	707.0000	.0306806	708.0000	.0307255	709.0000	.0307704
710.0000	.0308153	711.0000	.0308601	712.0000	.0309050	713.0000	.0309499	714.0000	.0309948
715.0000	.0310396	716.0000	.0310845	717.0000	.0311294	718.0000	.0311743	719.0000	.0312191
720.0000	.0312640	721.0000	.0313089	722.0000	.0313537	723.0000	.0313986	724.0000	.0314435
725.0000	.0314884	726.0000	.0315332	727.0000	.0315781	728.0000	.0316230	729.0000	.0316679
730.0000	.0317127	731.0000	.0317576	732.0000	.0318025	733.0000	.0318474	734.0000	.0318922
735.0000	.0319371	736.0000	.0319820	737.0000	.0320269	738.0000	.0320717	739.0000	.0321166
740.0000	.0321615	741.0000	.0322064	742.0000	.0322512	743.0000	.0322961	744.0000	.0323410
745.0000	.0323858	746.0000	.0324307	747.0000	.0324756	748.0000	.0325205	749.0000	.0325653
750.0000	.0326102	751.0000	.0326551	752.0000	.0327000	753.0000	.0327448	754.0000	.0327897
755.0000	.0328346	756.0000	.0328795	757.0000	.0329243	758.0000	.0329692	759.0000	.0330141
760.0000	.0330590	761.0000	.0331038	762.0000	.0331487	763.0000	.0331936	764.0000	.0332385
765.0000	.0332833	766.0000	.0333282	767.0000	.0333731	768.0000	.0334179	769.0000	.0334628
770.0000	.0335077	771.0000	.0335526	772.0000	.0335974	773.0000	.0336423	774.0000	.0336872
775.0000	.0337321	776.0000	.0337769	777.0000	.0338218	778.0000	.0338667	779.0000	.0339116
780.0000	.0339564	781.0000	.0340013	782.0000	.0340462	783.0000	.0340911	784.0000	.0341359
785.0000	.0341808	786.0000	.0342257	787.0000	.0342705	788.0000	.0343154	789.0000	.0343603
790.0000	.0344052	791.0000	.0344500	792.0000	.0344949	793.0000	.0345398	794.0000	.0345847
795.0000	.0346295	796.0000	.0346744	797.0000	.0347193	798.0000	.0347642	799.0000	.0348090

TEMPERATURE	24.80								
550.0000	.0234989	551.0000	.0235436	552.0000	.0235882	553.0000	.0236328	554.0000	.0236775
555.0000	.0237221	556.0000	.0237668	557.0000	.0238114	558.0000	.0238560	559.0000	.0239007
560.0000	.0239453	561.0000	.0239899	562.0000	.0240346	563.0000	.0240792	564.0000	.0241239
565.0000	.0241685	566.0000	.0242131	567.0000	.0242578	568.0000	.0243024	569.0000	.0243471
570.0000	.0243917	571.0000	.0244363	572.0000	.0244810	573.0000	.0245256	574.0000	.0245702
575.0000	.0246149	576.0000	.0246595	577.0000	.0247042	578.0000	.0247488	579.0000	.0247934
580.0000	.0248381	581.0000	.0248827	582.0000	.0249274	583.0000	.0249720	584.0000	.0250166
585.0000	.0250613	586.0000	.0251059	587.0000	.0251505	588.0000	.0251952	589.0000	.0252398
590.0000	.0252845	591.0000	.0253291	592.0000	.0253737	593.0000	.0254184	594.0000	.0254630
595.0000	.0255077	596.0000	.0255523	597.0000	.0255969	598.0000	.0256416	599.0000	.0256862
600.0000	.0257308	601.0000	.0257755	602.0000	.0258201	603.0000	.0258648	604.0000	.0259094
605.0000	.0259540	606.0000	.0259987	607.0000	.0260433	608.0000	.0260880	609.0000	.0261326
610.0000	.0261772	611.0000	.0262219	612.0000	.0262665	613.0000	.0263111	614.0000	.0263558
615.0000	.0264004	616.0000	.0264451	617.0000	.0264897	618.0000	.0265343	619.0000	.0265790
620.0000	.0266236	621.0000	.0266682	622.0000	.0267129	623.0000	.0267575	624.0000	.0268022
625.0000	.0268468	626.0000	.0268914	627.0000	.0269361	628.0000	.0269807	629.0000	.0270254
630.0000	.0270700	631.0000	.0271146	632.0000	.0271593	633.0000	.0272039	634.0000	.0272485
635.0000	.0272932	636.0000	.0273378	637.0000	.0273825	638.0000	.0274271	639.0000	.0274717
640.0000	.0275164	641.0000	.0275610	642.0000	.0276057	643.0000	.0276503	644.0000	.0276949
645.0000	.0277396	646.0000	.0277842	647.0000	.0278288	648.0000	.0278735	649.0000	.0279181
650.0000	.0279628	651.0000	.0280074	652.0000	.0280520	653.0000	.0280967	654.0000	.0281413
655.0000	.0281860	656.0000	.0282306	657.0000	.0282752	658.0000	.0283199	659.0000	.0283645
660.0000	.0284091	661.0000	.0284538	662.0000	.0284984	663.0000	.0285431	664.0000	.0285877
665.0000	.0286323	666.0000	.0286770	667.0000	.0287216	668.0000	.0287663	669.0000	.0288109
670.0000	.0288555	671.0000	.0289002	672.0000	.0289448	673.0000	.0289894	674.0000	.0290341
675.0000	.0290787	676.0000	.0291234	677.0000	.0291680	678.0000	.0292126	679.0000	.0292573
680.0000	.0293019	681.0000	.0293466	682.0000	.0293912	683.0000	.0294358	684.0000	.0294805
685.0000	.0295251	686.0000	.0295697	687.0000	.0296144	688.0000	.0296590	689.0000	.0297037
690.0000	.0297483	691.0000	.0297929	692.0000	.0298376	693.0000	.0298822	694.0000	.0299269
695.0000	.0299715	696.0000	.0300161	697.0000	.0300608	698.0000	.0301054	699.0000	.0301500
700.0000	.0301947	701.0000	.0302393	702.0000	.0302840	703.0000	.0303286	704.0000	.0303732
705.0000	.0304179	706.0000	.0304625	707.0000	.0305071	708.0000	.0305518	709.0000	.0305964
710.0000	.0306411	711.0000	.0306857	712.0000	.0307303	713.0000	.0307750	714.0000	.0308196
715.0000	.0308643	716.0000	.0309089	717.0000	.0309535	718.0000	.0309982	719.0000	.0310428
720.0000	.0310874	721.0000	.0311321	722.0000	.0311767	723.0000	.0312214	724.0000	.0312660
725.0000	.0313106	726.0000	.0313553	727.0000	.0313999	728.0000	.0314446	729.0000	.0314892
730.0000	.0315338	731.0000	.0315785	732.0000	.0316231	733.0000	.0316677	734.0000	.0317124
735.0000	.0317570	736.0000	.0318017	737.0000	.0318463	738.0000	.0318909	739.0000	.0319356
740.0000	.0319802	741.0000	.0320249	742.0000	.0320695	743.0000	.0321141	744.0000	.0321588
745.0000	.0322034	746.0000	.0322480	747.0000	.0322927	748.0000	.0323373	749.0000	.0323820
750.0000	.0324266	751.0000	.0324712	752.0000	.0325159	753.0000	.0325605	754.0000	.0326052
755.0000	.0326498	756.0000	.0326944	757.0000	.0327391	758.0000	.0327837	759.0000	.0328283
760.0000	.0328730	761.0000	.0329176	762.0000	.0329623	763.0000	.0330069	764.0000	.0330515
765.0000	.0330962	766.							

TABLE 3—Continued

TEMPERATURE	25.00								
550.0000	.0233625	551.0000	.0234069	552.0000	.0234513	553.0000	.0234957	554.0000	.0235401
555.0000	.0235845	556.0000	.0236289	557.0000	.0236733	558.0000	.0237177	559.0000	.0237621
560.0000	.0238065	561.0000	.0238509	562.0000	.0238953	563.0000	.0239397	564.0000	.0239841
565.0000	.0240285	566.0000	.0240729	567.0000	.0241173	568.0000	.0241617	569.0000	.0242061
570.0000	.0242505	571.0000	.0242949	572.0000	.0243393	573.0000	.0243837	574.0000	.0244281
575.0000	.0244725	576.0000	.0245169	577.0000	.0245613	578.0000	.0246057	579.0000	.0246501
580.0000	.0246945	581.0000	.0247389	582.0000	.0247833	583.0000	.0248277	584.0000	.0248722
585.0000	.0249166	586.0000	.0249610	587.0000	.0250054	588.0000	.0250498	589.0000	.0250942
590.0000	.0251386	591.0000	.0251830	592.0000	.0252274	593.0000	.0252718	594.0000	.0253162
595.0000	.0253606	596.0000	.0254050	597.0000	.0254494	598.0000	.0254938	599.0000	.0255382
600.0000	.0255826	601.0000	.0256270	602.0000	.0256714	603.0000	.0257158	604.0000	.0257602
605.0000	.0258046	606.0000	.0258490	607.0000	.0258934	608.0000	.0259378	609.0000	.0259822
610.0000	.0260266	611.0000	.0260710	612.0000	.0261154	613.0000	.0261598	614.0000	.0262042
615.0000	.0262486	616.0000	.0262930	617.0000	.0263374	618.0000	.0263818	619.0000	.0264263
620.0000	.0264707	621.0000	.0265151	622.0000	.0265595	623.0000	.0266039	624.0000	.0266483
625.0000	.0266927	626.0000	.0267371	627.0000	.0267815	628.0000	.0268259	629.0000	.0268703
630.0000	.0269147	631.0000	.0269591	632.0000	.0270035	633.0000	.0270479	634.0000	.0270923
635.0000	.0271367	636.0000	.0271811	637.0000	.0272255	638.0000	.0272699	639.0000	.0273143
640.0000	.0273587	641.0000	.0274031	642.0000	.0274475	643.0000	.0274919	644.0000	.0275363
645.0000	.0275807	646.0000	.0276251	647.0000	.0276695	648.0000	.0277139	649.0000	.0277583
650.0000	.0278027	651.0000	.0278471	652.0000	.0278915	653.0000	.0279359	654.0000	.0279803
655.0000	.0280248	656.0000	.0280692	657.0000	.0281136	658.0000	.0281580	659.0000	.0282024
660.0000	.0282468	661.0000	.0282912	662.0000	.0283356	663.0000	.0283800	664.0000	.0284244
665.0000	.0284688	666.0000	.0285132	667.0000	.0285576	668.0000	.0286020	669.0000	.0286464
670.0000	.0286908	671.0000	.0287352	672.0000	.0287796	673.0000	.0288240	674.0000	.0288684
675.0000	.0289128	676.0000	.0289572	677.0000	.0290016	678.0000	.0290460	679.0000	.0290904
680.0000	.0291348	681.0000	.0291792	682.0000	.0292236	683.0000	.0292680	684.0000	.0293124
685.0000	.0293568	686.0000	.0294012	687.0000	.0294456	688.0000	.0294900	689.0000	.0295344
690.0000	.0295789	691.0000	.0296233	692.0000	.0296677	693.0000	.0297121	694.0000	.0297565
695.0000	.0298009	696.0000	.0298453	697.0000	.0298897	698.0000	.0299341	699.0000	.0299785
700.0000	.0300229	701.0000	.0300673	702.0000	.0301117	703.0000	.0301561	704.0000	.0302005
705.0000	.0302449	706.0000	.0302893	707.0000	.0303337	708.0000	.0303781	709.0000	.0304225
710.0000	.0304669	711.0000	.0305113	712.0000	.0305557	713.0000	.0306001	714.0000	.0306445
715.0000	.0306889	716.0000	.0307333	717.0000	.0307777	718.0000	.0308221	719.0000	.0308665
720.0000	.0309109	721.0000	.0309553	722.0000	.0309997	723.0000	.0310441	724.0000	.0310885
725.0000	.0311330	726.0000	.0311774	727.0000	.0312218	728.0000	.0312662	729.0000	.0313106
730.0000	.0313550	731.0000	.0313994	732.0000	.0314438	733.0000	.0314882	734.0000	.0315326
735.0000	.0315770	736.0000	.0316214	737.0000	.0316658	738.0000	.0317102	739.0000	.0317546
740.0000	.0317990	741.0000	.0318434	742.0000	.0318878	743.0000	.0319322	744.0000	.0319766
745.0000	.0320210	746.0000	.0320654	747.0000	.0321098	748.0000	.0321542	749.0000	.0321986
750.0000	.0322430	751.0000	.0322874	752.0000	.0323318	753.0000	.0323762	754.0000	.0324206
755.0000	.0324650	756.0000	.0325094	757.0000	.0325538	758.0000	.0325982	759.0000	.0326426
760.0000	.0326871	761.0000	.0327315	762.0000	.0327759	763.0000	.0328203	764.0000	.0328647
765.0000	.0329091	766.0000	.0329535	767.0000	.0329979	768.0000	.0330423	769.0000	.0330867
770.0000	.0331311	771.0000	.0331755	772.0000	.0332199	773.0000	.0332643	774.0000	.0333087
775.0000	.0333531	776.0000	.0333975	777.0000	.0334419	778.0000	.0334863	779.0000	.0335307
780.0000	.0335751	781.0000	.0336195	782.0000	.0336639	783.0000	.0337083	784.0000	.0337527
785.0000	.0337971	786.0000	.0338415	787.0000	.0338859	788.0000	.0339303	789.0000	.0339747
790.0000	.0340191	791.0000	.0340635	792.0000	.0341079	793.0000	.0341523	794.0000	.0341967
795.0000	.0342412	796.0000	.0342856	797.0000	.0343300	798.0000	.0343744	799.0000	.0344188

TEMPERATURE	25.20								
550.0000	.0232260	551.0000	.0232702	552.0000	.0233143	553.0000	.0233585	554.0000	.0234027
555.0000	.0234468	556.0000	.0234910	557.0000	.0235352	558.0000	.0235793	559.0000	.0236235
560.0000	.0236677	561.0000	.0237118	562.0000	.0237560	563.0000	.0238002	564.0000	.0238443
565.0000	.0238885	566.0000	.0239327	567.0000	.0239768	568.0000	.0240210	569.0000	.0240652
570.0000	.0241093	571.0000	.0241535	572.0000	.0241977	573.0000	.0242418	574.0000	.0242860
575.0000	.0243302	576.0000	.0243743	577.0000	.0244185	578.0000	.0244627	579.0000	.0245068
580.0000	.0245510	581.0000	.0245952	582.0000	.0246393	583.0000	.0246835	584.0000	.0247277
585.0000	.0247718	586.0000	.0248160	587.0000	.0248602	588.0000	.0249043	589.0000	.0249485
590.0000	.0249927	591.0000	.0250369	592.0000	.0250810	593.0000	.0251252	594.0000	.0251694
595.0000	.0252135	596.0000	.0252577	597.0000	.0253019	598.0000	.0253460	599.0000	.0253902
600.0000	.0254344	601.0000	.0254785	602.0000	.0255227	603.0000	.0255669	604.0000	.0256110
605.0000	.0256552	606.0000	.0256994	607.0000	.0257435	608.0000	.0257877	609.0000	.0258319
610.0000	.0258760	611.0000	.0259202	612.0000	.0259644	613.0000	.0260085	614.0000	.0260527
615.0000	.0260969	616.0000	.0261410	617.0000	.0261852	618.0000	.0262294	619.0000	.0262735
620.0000	.0263177	621.0000	.0263619	622.0000	.0264060	623.0000	.0264502	624.0000	.0264944
625.0000	.0265385	626.0000	.0265827	627.0000	.0266269	628.0000	.0266710	629.0000	.0267152
630.0000	.0267594	631.0000	.0268035	632.0000	.0268477	633.0000	.0268919	634.0000	.0269361
635.0000	.0269802	636.0000	.0270244	637.0000	.0270686	638.0000	.0271127	639.0000	.0271569
640.0000	.0272011	641.0000	.0272452	642.0000	.0272894	643.0000	.0273336	644.0000	.0273777
645.0000	.0274219	646.0000	.0274661	647.0000	.0275102	648.0000	.0275544	649.0000	.0275986
650.0000	.0276427	651.0000	.0276869	652.0000	.0277311	653.0000	.0277752	654.0000	.0278194
655.0000	.0278636	656.0000	.0279077	657.0000	.0279519	658.0000	.0279961	659.0000	.0280402
660.0000	.0280844	661.0000	.0281286	662.0000	.0281727	663.0000	.0282169	664.0000	.0282611
665.0000	.0283052	666.0000	.0283494	667.0000	.0283936	668.0000	.0284377	669.0000	.0284819
670.0000	.0285261	671.0000	.0285702	672.0000	.0286144	673.0000	.0286586	674.0000	.0287027
675.0000	.0287469	676.0000	.0287911	677.0000	.0288353	678.0000	.0288794	679.0000	.0289236
680.0000	.0289678	681.0000	.0290119	682.0000	.0290561	683.0000	.0291003	684.0000	.0291444
685.0000	.0291886	686.0000	.0292328	687.0000	.0292769	688.0000	.0293211	689.0000	.0293653
690.0000	.0294094	691.0000	.0294536	692.0000	.0294978	693.0000	.0295419	694.0000	.0295861
695.0000	.0296303	696.0000	.0296744	697.0000	.0297186	698.0000	.0297628	699.0000	.0298069
700.0000	.0298511	701.0000	.0298953	702.0000	.0299394	703.0000	.0299836	704.0000	.0300278
705.0000	.0300719	706.0000	.0301161	707.0000	.0301603	708.0000	.0302045	709.0000	.0302486
710.0000	.0302928	711.0000	.0303369	712.0000	.0303811	713.0000	.0304253	714.0000	.0304694
715.0000	.0305136	716.0000	.0305578	717.0000	.0306020	718.0000	.0306461	719.0000	.0306903
720.0000	.0307345	721.0000	.0307786	722.0000	.0308228	723.0000	.0308670	724.0000	.0309111
725.0000	.0309553	726.0000	.0309995	727.0000	.0310436	728.0000	.0310878	729.0000	.0311320
730.0000	.0311761	731.0000	.0312203	732.0000	.0312645	733.0000	.0313086	734.0000	.0313528
735.0000	.0313970	736.0000	.0314411	737.0000	.0314853	738.0000	.0315295	739.0000	.0315736
740.0000	.0316178	741.0000	.0316620	742.0000	.0317061	743.0000	.0317503	744.0000	.0317945
745.0000	.0318386	746.0000	.0318828	747.0000	.0319270	748.0000	.0319711	749.0000	.0320153
750.0000	.0320595	751.0000	.0321036	752.0000	.0321478	753.0000	.0321920	754.0000	.0322361
755.0000	.0322803	756.0000	.0323245	757.0000	.0323687	758.0000	.0324128	759.0000	.0324570
760.0000	.0325012	761.0000	.0325453	762.0000	.0325895	763.0000	.0326337	764.0000	.0326778
765.0000	.0327220	766.							

TABLE 3—Continued

TEMPERATURE		25.40							
550.0000	.0230587	551.0000	.0231026	552.0000	.0231465	553.0000	.0231904	554.0000	.0232342
555.0000	.0232781	556.0000	.0233220	557.0000	.0233659	558.0000	.0234097	559.0000	.0234536
560.0000	.0234975	561.0000	.0235413	562.0000	.0235852	563.0000	.0236291	564.0000	.0236730
565.0000	.0237168	566.0000	.0237607	567.0000	.0238046	568.0000	.0238485	569.0000	.0238923
570.0000	.0239362	571.0000	.0239801	572.0000	.0240240	573.0000	.0240678	574.0000	.0241117
575.0000	.0241556	576.0000	.0241995	577.0000	.0242433	578.0000	.0242872	579.0000	.0243311
580.0000	.0243749	581.0000	.0244188	582.0000	.0244627	583.0000	.0245066	584.0000	.0245504
585.0000	.0245943	586.0000	.0246382	587.0000	.0246821	588.0000	.0247259	589.0000	.0247698
590.0000	.0248137	591.0000	.0248576	592.0000	.0249014	593.0000	.0249453	594.0000	.0249892
595.0000	.0250330	596.0000	.0250769	597.0000	.0251208	598.0000	.0251647	599.0000	.0252085
600.0000	.0252524	601.0000	.0252963	602.0000	.0253402	603.0000	.0253840	604.0000	.0254279
605.0000	.0254718	606.0000	.0255157	607.0000	.0255595	608.0000	.0256034	609.0000	.0256473
610.0000	.0256912	611.0000	.0257350	612.0000	.0257789	613.0000	.0258228	614.0000	.0258666
615.0000	.0259105	616.0000	.0259544	617.0000	.0259983	618.0000	.0260421	619.0000	.0260860
620.0000	.0261299	621.0000	.0261738	622.0000	.0262176	623.0000	.0262615	624.0000	.0263054
625.0000	.0263493	626.0000	.0263931	627.0000	.0264370	628.0000	.0264809	629.0000	.0265247
630.0000	.0265686	631.0000	.0266125	632.0000	.0266564	633.0000	.0267002	634.0000	.0267441
635.0000	.0267880	636.0000	.0268319	637.0000	.0268757	638.0000	.0269196	639.0000	.0269635
640.0000	.0270074	641.0000	.0270512	642.0000	.0270951	643.0000	.0271390	644.0000	.0271829
645.0000	.0272267	646.0000	.0272706	647.0000	.0273145	648.0000	.0273583	649.0000	.0274022
650.0000	.0274461	651.0000	.0274900	652.0000	.0275338	653.0000	.0275777	654.0000	.0276216
655.0000	.0276655	656.0000	.0277093	657.0000	.0277532	658.0000	.0277971	659.0000	.0278410
660.0000	.0278848	661.0000	.0279287	662.0000	.0279726	663.0000	.0280164	664.0000	.0280603
665.0000	.0281042	666.0000	.0281481	667.0000	.0281919	668.0000	.0282358	669.0000	.0282797
670.0000	.0283236	671.0000	.0283674	672.0000	.0284113	673.0000	.0284552	674.0000	.0284991
675.0000	.0285429	676.0000	.0285868	677.0000	.0286307	678.0000	.0286746	679.0000	.0287184
680.0000	.0287623	681.0000	.0288062	682.0000	.0288500	683.0000	.0288939	684.0000	.0289378
685.0000	.0289817	686.0000	.0290255	687.0000	.0290694	688.0000	.0291133	689.0000	.0291572
690.0000	.0292010	691.0000	.0292449	692.0000	.0292888	693.0000	.0293327	694.0000	.0293765
695.0000	.0294204	696.0000	.0294643	697.0000	.0295081	698.0000	.0295520	699.0000	.0295959
700.0000	.0296398	701.0000	.0296836	702.0000	.0297275	703.0000	.0297714	704.0000	.0298153
705.0000	.0298591	706.0000	.0299030	707.0000	.0299469	708.0000	.0299908	709.0000	.0300346
710.0000	.0300785	711.0000	.0301224	712.0000	.0301662	713.0000	.0302101	714.0000	.0302540
715.0000	.0302979	716.0000	.0303417	717.0000	.0303856	718.0000	.0304295	719.0000	.0304734
720.0000	.0305172	721.0000	.0305611	722.0000	.0306050	723.0000	.0306489	724.0000	.0306927
725.0000	.0307366	726.0000	.0307805	727.0000	.0308244	728.0000	.0308682	729.0000	.0309121
730.0000	.0309560	731.0000	.0309998	732.0000	.0310437	733.0000	.0310876	734.0000	.0311315
735.0000	.0311753	736.0000	.0312192	737.0000	.0312631	738.0000	.0313070	739.0000	.0313508
740.0000	.0313947	741.0000	.0314386	742.0000	.0314825	743.0000	.0315263	744.0000	.0315702
745.0000	.0316141	746.0000	.0316579	747.0000	.0317018	748.0000	.0317457	749.0000	.0317896
750.0000	.0318334	751.0000	.0318773	752.0000	.0319212	753.0000	.0319651	754.0000	.0320089
755.0000	.0320528	756.0000	.0320967	757.0000	.0321406	758.0000	.0321844	759.0000	.0322283
760.0000	.0322722	761.0000	.0323161	762.0000	.0323599	763.0000	.0324038	764.0000	.0324477
765.0000	.0324915	766.0000	.0325354	767.0000	.0325793	768.0000	.0326232	769.0000	.0326670
770.0000	.0327109	771.0000	.0327548	772.0000	.0327987	773.0000	.0328425	774.0000	.0328864
775.0000	.0329303	776.0000	.0329742	777.0000	.0330180	778.0000	.0330619	779.0000	.0331058
780.0000	.0331496	781.0000	.0331935	782.0000	.0332374	783.0000	.0332813	784.0000	.0333251
785.0000	.0333690	786.0000	.0334129	787.0000	.0334568	788.0000	.0335006	789.0000	.0335445
790.0000	.0335884	791.0000	.0336323	792.0000	.0336761	793.0000	.0337200	794.0000	.0337639
795.0000	.0338078	796.0000	.0338516	797.0000	.0338955	798.0000	.0339394	799.0000	.0339832

TEMPERATURE		25.60							
550.0000	.0229222	551.0000	.0229659	552.0000	.0230095	553.0000	.0230531	554.0000	.0230968
555.0000	.0231404	556.0000	.0231841	557.0000	.0232277	558.0000	.0232713	559.0000	.0233150
560.0000	.0233586	561.0000	.0234022	562.0000	.0234459	563.0000	.0234895	564.0000	.0235332
565.0000	.0235768	566.0000	.0236204	567.0000	.0236641	568.0000	.0237077	569.0000	.0237513
570.0000	.0237950	571.0000	.0238386	572.0000	.0238823	573.0000	.0239259	574.0000	.0239695
575.0000	.0240132	576.0000	.0240568	577.0000	.0241005	578.0000	.0241441	579.0000	.0241877
580.0000	.0242314	581.0000	.0242750	582.0000	.0243186	583.0000	.0243623	584.0000	.0244059
585.0000	.0244496	586.0000	.0244932	587.0000	.0245368	588.0000	.0245805	589.0000	.0246241
590.0000	.0246677	591.0000	.0247114	592.0000	.0247550	593.0000	.0247987	594.0000	.0248423
595.0000	.0248859	596.0000	.0249296	597.0000	.0249732	598.0000	.0250169	599.0000	.0250605
600.0000	.0251041	601.0000	.0251478	602.0000	.0251914	603.0000	.0252350	604.0000	.0252787
605.0000	.0253223	606.0000	.0253660	607.0000	.0254096	608.0000	.0254532	609.0000	.0254969
610.0000	.0255405	611.0000	.0255841	612.0000	.0256278	613.0000	.0256714	614.0000	.0257151
615.0000	.0257587	616.0000	.0258023	617.0000	.0258460	618.0000	.0258896	619.0000	.0259333
620.0000	.0259769	621.0000	.0260205	622.0000	.0260642	623.0000	.0261078	624.0000	.0261514
625.0000	.0261951	626.0000	.0262387	627.0000	.0262824	628.0000	.0263260	629.0000	.0263696
630.0000	.0264133	631.0000	.0264569	632.0000	.0265005	633.0000	.0265442	634.0000	.0265878
635.0000	.0266315	636.0000	.0266751	637.0000	.0267187	638.0000	.0267624	639.0000	.0268060
640.0000	.0268497	641.0000	.0268933	642.0000	.0269369	643.0000	.0269806	644.0000	.0270242
645.0000	.0270678	646.0000	.0271115	647.0000	.0271551	648.0000	.0271988	649.0000	.0272424
650.0000	.0272860	651.0000	.0273297	652.0000	.0273733	653.0000	.0274169	654.0000	.0274606
655.0000	.0275042	656.0000	.0275479	657.0000	.0275915	658.0000	.0276351	659.0000	.0276788
660.0000	.0277224	661.0000	.0277661	662.0000	.0278097	663			

TABLE 3—Continued

TEMPERATURE 25.80									
550.0000	.0227857	551.0000	.0228291	552.0000	.0228725	553.0000	.0229159	554.0000	.0229593
555.0000	.0230027	556.0000	.0230461	557.0000	.0230895	558.0000	.0231329	559.0000	.0231763
560.0000	.0232197	561.0000	.0232631	562.0000	.0233065	563.0000	.0233499	564.0000	.0233933
565.0000	.0234367	566.0000	.0234801	567.0000	.0235235	568.0000	.0235669	569.0000	.0236103
570.0000	.0236537	571.0000	.0236971	572.0000	.0237405	573.0000	.0237839	574.0000	.0238273
575.0000	.0238707	576.0000	.0239142	577.0000	.0239576	578.0000	.0240010	579.0000	.0240444
580.0000	.0240878	581.0000	.0241312	582.0000	.0241746	583.0000	.0242180	584.0000	.0242614
585.0000	.0243048	586.0000	.0243482	587.0000	.0243916	588.0000	.0244350	589.0000	.0244784
590.0000	.0245218	591.0000	.0245652	592.0000	.0246086	593.0000	.0246520	594.0000	.0246954
595.0000	.0247388	596.0000	.0247822	597.0000	.0248256	598.0000	.0248690	599.0000	.0249124
600.0000	.0249558	601.0000	.0249992	602.0000	.0250426	603.0000	.0250860	604.0000	.0251294
605.0000	.0251728	606.0000	.0252162	607.0000	.0252596	608.0000	.0253030	609.0000	.0253464
610.0000	.0253898	611.0000	.0254332	612.0000	.0254766	613.0000	.0255201	614.0000	.0255635
615.0000	.0256069	616.0000	.0256503	617.0000	.0256937	618.0000	.0257371	619.0000	.0257805
620.0000	.0258239	621.0000	.0258673	622.0000	.0259107	623.0000	.0259541	624.0000	.0259975
625.0000	.0260409	626.0000	.0260843	627.0000	.0261277	628.0000	.0261711	629.0000	.0262145
630.0000	.0262579	631.0000	.0263013	632.0000	.0263447	633.0000	.0263881	634.0000	.0264315
635.0000	.0264749	636.0000	.0265183	637.0000	.0265617	638.0000	.0266051	639.0000	.0266485
640.0000	.0266919	641.0000	.0267353	642.0000	.0267787	643.0000	.0268221	644.0000	.0268655
645.0000	.0269089	646.0000	.0269523	647.0000	.0269957	648.0000	.0270391	649.0000	.0270825
650.0000	.0271259	651.0000	.0271694	652.0000	.0272128	653.0000	.0272562	654.0000	.0272996
655.0000	.0273430	656.0000	.0273864	657.0000	.0274298	658.0000	.0274732	659.0000	.0275166
660.0000	.0275600	661.0000	.0276034	662.0000	.0276468	663.0000	.0276902	664.0000	.0277336
665.0000	.0277770	666.0000	.0278204	667.0000	.0278638	668.0000	.0279072	669.0000	.0279506
670.0000	.0279940	671.0000	.0280374	672.0000	.0280808	673.0000	.0281242	674.0000	.0281676
675.0000	.0282110	676.0000	.0282544	677.0000	.0282978	678.0000	.0283412	679.0000	.0283846
680.0000	.0284280	681.0000	.0284714	682.0000	.0285148	683.0000	.0285582	684.0000	.0286016
685.0000	.0286450	686.0000	.0286884	687.0000	.0287318	688.0000	.0287753	689.0000	.0288187
690.0000	.0288621	691.0000	.0289055	692.0000	.0289489	693.0000	.0289923	694.0000	.0290357
695.0000	.0290791	696.0000	.0291225	697.0000	.0291659	698.0000	.0292093	699.0000	.0292527
700.0000	.0292961	701.0000	.0293395	702.0000	.0293829	703.0000	.0294263	704.0000	.0294697
705.0000	.0295131	706.0000	.0295565	707.0000	.0295999	708.0000	.0296433	709.0000	.0296867
710.0000	.0297301	711.0000	.0297735	712.0000	.0298169	713.0000	.0298603	714.0000	.0299037
715.0000	.0299471	716.0000	.0299905	717.0000	.0300339	718.0000	.0300773	719.0000	.0301207
720.0000	.0301641	721.0000	.0302075	722.0000	.0302509	723.0000	.0302943	724.0000	.0303377
725.0000	.0303812	726.0000	.0304246	727.0000	.0304680	728.0000	.0305114	729.0000	.0305548
730.0000	.0305982	731.0000	.0306416	732.0000	.0306850	733.0000	.0307284	734.0000	.0307718
735.0000	.0308152	736.0000	.0308586	737.0000	.0309020	738.0000	.0309454	739.0000	.0309888
740.0000	.0310322	741.0000	.0310756	742.0000	.0311190	743.0000	.0311624	744.0000	.0312058
745.0000	.0312492	746.0000	.0312926	747.0000	.0313360	748.0000	.0313794	749.0000	.0314228
750.0000	.0314662	751.0000	.0315096	752.0000	.0315530	753.0000	.0315964	754.0000	.0316398
755.0000	.0316832	756.0000	.0317266	757.0000	.0317700	758.0000	.0318134	759.0000	.0318568
760.0000	.0319002	761.0000	.0319436	762.0000	.0319871	763.0000	.0320305	764.0000	.0320739
765.0000	.0321173	766.0000	.0321607	767.0000	.0322041	768.0000	.0322475	769.0000	.0322909
770.0000	.0323343	771.0000	.0323777	772.0000	.0324211	773.0000	.0324645	774.0000	.0325079
775.0000	.0325513	776.0000	.0325947	777.0000	.0326381	778.0000	.0326815	779.0000	.0327249
780.0000	.0327683	781.0000	.0328117	782.0000	.0328551	783.0000	.0328985	784.0000	.0329419
785.0000	.0329853	786.0000	.0330287	787.0000	.0330721	788.0000	.0331155	789.0000	.0331589
790.0000	.0332023	791.0000	.0332457	792.0000	.0332891	793.0000	.0333325	794.0000	.0333759
795.0000	.0334193	796.0000	.0334627	797.0000	.0335061	798.0000	.0335495	799.0000	.0335930
TEMPERATURE 26.00									
550.0000	.0226492	551.0000	.0226924	552.0000	.0227355	553.0000	.0227787	554.0000	.0228219
555.0000	.0228650	556.0000	.0229082	557.0000	.0229514	558.0000	.0229945	559.0000	.0230377
560.0000	.0230809	561.0000	.0231240	562.0000	.0231672	563.0000	.0232104	564.0000	.0232535
565.0000	.0232967	566.0000	.0233399	567.0000	.0233830	568.0000	.0234262	569.0000	.0234694
570.0000	.0235125	571.0000	.0235557	572.0000	.0235989	573.0000	.0236420	574.0000	.0236852
575.0000	.0237284	576.0000	.0237715	577.0000	.0238147	578.0000	.0238579	579.0000	.0239010
580.0000	.0239442	581.0000	.0239874	582.0000	.0240305	583.0000	.0240737	584.0000	.0241169
585.0000	.0241601	586.0000	.0242032	587.0000	.0242464	588.0000	.0242896	589.0000	.0243327
590.0000	.0243759	591.0000	.0244191	592.0000	.0244622	593.0000	.0245054	594.0000	.0245486
595.0000	.0245917	596.0000	.0246349	597.0000	.0246781	598.0000	.0247212	599.0000	.0247644
600.0000	.0248076	601.0000	.0248507	602.0000	.0248939	603.0000	.0249371	604.0000	.0249802
605.0000	.0250234	606.0000	.0250666	607.0000	.0251097	608.0000	.0251529	609.0000	.0251961
610.0000	.0252392	611.0000	.0252824	612.0000	.0253256	613.0000	.0253687	614.0000	.0254119
615.0000	.0254551	616.0000	.0254982	617.0000	.0255414	618.0000	.0255846	619.0000	.0256277
620.0000	.0256709	621.0000	.0257141	622.0000	.0257572	623.0000	.0258004	624.0000	.0258436
625.0000	.0258867	626.0000	.0259299	627.0000	.0259731	628.0000	.0260162	629.0000	.0260594
630.0000	.0261026	631.0000	.0261457	632.0000	.0261889	633.0000	.0262321	634.0000	.0262752
635.0000	.0263184	636.0000	.0263616	637.0000	.0264048	638.0000	.0264479	639.0000	.0264911
640.0000	.0265343	641.0000	.0265774	642.0000	.0266206	643.0000	.0266638	644.0000	.0267069
645.0000	.0267501	646.0000	.0267933	647.0000	.0268364	648.0000	.0268796	649.0000	.0269228
650.0000	.0269659	651.0000	.0270091	652.0000	.0270523	653.0000	.0270954	654.0000	.0271386
655.0000	.0271818	656.0000	.0272249	657.0000	.0272681	658.0000	.0273113	659.0000	.0273544
660.0000	.0273976	661.0000	.0274408	662.0000	.0274839	663.0000	.0275271	664.0000	.0275703
665.0000	.0276134	666.0000	.0276566	667.0000	.0276998	668.0			

TABLE 3—Continued

TEMPERATURE 26.20									
550.0000	.0225127	551.0000	.0225557	552.0000	.0225986	553.0000	.0226415	554.0000	.0226845
555.0000	.0227274	556.0000	.0227703	557.0000	.0228133	558.0000	.0228562	559.0000	.0228991
560.0000	.0229420	561.0000	.0229850	562.0000	.0230279	563.0000	.0230708	564.0000	.0231138
565.0000	.0231567	566.0000	.0231996	567.0000	.0232426	568.0000	.0232855	569.0000	.0233284
570.0000	.0233714	571.0000	.0234143	572.0000	.0234572	573.0000	.0235002	574.0000	.0235431
575.0000	.0235860	576.0000	.0236290	577.0000	.0236719	578.0000	.0237148	579.0000	.0237578
580.0000	.0238007	581.0000	.0238436	582.0000	.0238866	583.0000	.0239295	584.0000	.0239724
585.0000	.0240153	586.0000	.0240583	587.0000	.0241012	588.0000	.0241441	589.0000	.0241871
590.0000	.0242300	591.0000	.0242729	592.0000	.0243159	593.0000	.0243588	594.0000	.0244017
595.0000	.0244447	596.0000	.0244876	597.0000	.0245305	598.0000	.0245735	599.0000	.0246164
600.0000	.0246593	601.0000	.0247023	602.0000	.0247452	603.0000	.0247881	604.0000	.0248311
605.0000	.0248740	606.0000	.0249169	607.0000	.0249599	608.0000	.0250028	609.0000	.0250457
610.0000	.0250886	611.0000	.0251316	612.0000	.0251745	613.0000	.0252174	614.0000	.0252604
615.0000	.0253033	616.0000	.0253462	617.0000	.0253892	618.0000	.0254321	619.0000	.0254750
620.0000	.0255180	621.0000	.0255609	622.0000	.0256038	623.0000	.0256468	624.0000	.0256897
625.0000	.0257326	626.0000	.0257756	627.0000	.0258185	628.0000	.0258614	629.0000	.0259044
630.0000	.0259473	631.0000	.0259902	632.0000	.0260331	633.0000	.0260761	634.0000	.0261190
635.0000	.0261619	636.0000	.0262049	637.0000	.0262478	638.0000	.0262907	639.0000	.0263337
640.0000	.0263766	641.0000	.0264195	642.0000	.0264625	643.0000	.0265054	644.0000	.0265483
645.0000	.0265913	646.0000	.0266342	647.0000	.0266771	648.0000	.0267201	649.0000	.0267630
650.0000	.0268059	651.0000	.0268489	652.0000	.0268918	653.0000	.0269347	654.0000	.0269777
655.0000	.0270206	656.0000	.0270635	657.0000	.0271064	658.0000	.0271494	659.0000	.0271923
660.0000	.0272352	661.0000	.0272782	662.0000	.0273211	663.0000	.0273640	664.0000	.0274070
665.0000	.0274499	666.0000	.0274928	667.0000	.0275358	668.0000	.0275787	669.0000	.0276216
670.0000	.0276646	671.0000	.0277075	672.0000	.0277504	673.0000	.0277934	674.0000	.0278363
675.0000	.0278792	676.0000	.0279222	677.0000	.0279651	678.0000	.0280080	679.0000	.0280510
680.0000	.0280939	681.0000	.0281368	682.0000	.0281797	683.0000	.0282227	684.0000	.0282656
685.0000	.0283085	686.0000	.0283515	687.0000	.0283944	688.0000	.0284373	689.0000	.0284803
690.0000	.0285232	691.0000	.0285661	692.0000	.0286091	693.0000	.0286520	694.0000	.0286949
695.0000	.0287379	696.0000	.0287808	697.0000	.0288237	698.0000	.0288667	699.0000	.0289096
700.0000	.0289525	701.0000	.0289955	702.0000	.0290384	703.0000	.0290813	704.0000	.0291242
705.0000	.0291672	706.0000	.0292101	707.0000	.0292530	708.0000	.0292960	709.0000	.0293389
710.0000	.0293818	711.0000	.0294248	712.0000	.0294677	713.0000	.0295106	714.0000	.0295536
715.0000	.0295965	716.0000	.0296394	717.0000	.0296824	718.0000	.0297253	719.0000	.0297682
720.0000	.0298112	721.0000	.0298541	722.0000	.0298970	723.0000	.0299400	724.0000	.0299829
725.0000	.0300258	726.0000	.0300688	727.0000	.0301117	728.0000	.0301546	729.0000	.0301975
730.0000	.0302405	731.0000	.0302834	732.0000	.0303263	733.0000	.0303693	734.0000	.0304122
735.0000	.0304551	736.0000	.0304981	737.0000	.0305410	738.0000	.0305839	739.0000	.0306269
740.0000	.0306698	741.0000	.0307127	742.0000	.0307557	743.0000	.0307986	744.0000	.0308415
745.0000	.0308845	746.0000	.0309274	747.0000	.0309703	748.0000	.0310133	749.0000	.0310562
750.0000	.0310991	751.0000	.0311420	752.0000	.0311850	753.0000	.0312279	754.0000	.0312708
755.0000	.0313138	756.0000	.0313567	757.0000	.0313996	758.0000	.0314426	759.0000	.0314855
760.0000	.0315284	761.0000	.0315714	762.0000	.0316143	763.0000	.0316572	764.0000	.0317002
765.0000	.0317431	766.0000	.0317860	767.0000	.0318290	768.0000	.0318719	769.0000	.0319148
770.0000	.0319578	771.0000	.0320007	772.0000	.0320436	773.0000	.0320866	774.0000	.0321295
775.0000	.0321724	776.0000	.0322153	777.0000	.0322583	778.0000	.0323012	779.0000	.0323441
780.0000	.0323871	781.0000	.0324300	782.0000	.0324729	783.0000	.0325159	784.0000	.0325588
785.0000	.0326017	786.0000	.0326447	787.0000	.0326876	788.0000	.0327305	789.0000	.0327735
790.0000	.0328164	791.0000	.0328593	792.0000	.0329023	793.0000	.0329452	794.0000	.0329881
795.0000	.0330311	796.0000	.0330740	797.0000	.0331169	798.0000	.0331599	799.0000	.0332028
TEMPERATURE 26.40									
550.0000	.0223763	551.0000	.0224190	552.0000	.0224617	553.0000	.0225044	554.0000	.0225471
555.0000	.0225898	556.0000	.0226325	557.0000	.0226752	558.0000	.0227179	559.0000	.0227606
560.0000	.0228033	561.0000	.0228459	562.0000	.0228886	563.0000	.0229313	564.0000	.0229740
565.0000	.0230167	566.0000	.0230594	567.0000	.0231021	568.0000	.0231448	569.0000	.0231875
570.0000	.0232302	571.0000	.0232729	572.0000	.0233156	573.0000	.0233583	574.0000	.0234010
575.0000	.0234437	576.0000	.0234864	577.0000	.0235291	578.0000	.0235718	579.0000	.0236145
580.0000	.0236572	581.0000	.0236999	582.0000	.0237426	583.0000	.0237853	584.0000	.0238280
585.0000	.0238707	586.0000	.0239134	587.0000	.0239561	588.0000	.0239988	589.0000	.0240415
590.0000	.0240841	591.0000	.0241268	592.0000	.0241695	593.0000	.0242122	594.0000	.0242549
595.0000	.0242976	596.0000	.0243403	597.0000	.0243830	598.0000	.0244257	599.0000	.0244684
600.0000	.0245111	601.0000	.0245538	602.0000	.0245965	603.0000	.0246392	604.0000	.0246819
605.0000	.0247246	606.0000	.0247673	607.0000	.0248100	608.0000	.0248527	609.0000	.0248954
610.0000	.0249381	611.0000	.0249808	612.0000	.0250235	613.0000	.0250662	614.0000	.0251089
615.0000	.0251516	616.0000	.0251943	617.0000	.0252370	618.0000	.0252797	619.0000	.0253223
620.0000	.0253650	621.0000	.0254077	622.0000	.0254504	623.0000	.0254931	624.0000	.0255358
625.0000	.0255785	626.0000	.0256212	627.0000	.0256639	628.0000	.0257066	629.0000	.0257493
630.0000	.0257920	631.0000	.0258347	632.0000	.0258774	633.0000	.0259201	634.0000	.0259628
635.0000	.0260055	636.0000	.0260482	637.0000	.0260909	638.0000	.0261336	639.0000	.0261763
640.0000	.0262190	641.0000	.0262617	642.0000	.0263044	643.0000	.0263471	644.0000	.0263898
645.0000	.0264325	646.0000	.0264752	647.0000	.0265179	648.0000	.0265606	649.0000	.0266032
650.0000	.0266459	651.0000	.0266886	652.0000	.0267313	653.0000	.0267740	654.0000	.0268167
655.0000	.0268594	656.0000	.0269021	657.0000	.0269448	658.0000	.0269875	659.0000	.0270302
660.0000	.0270724	661.0000	.0271151	662.0000	.0271578	663.0000	.0272005	664.0000	.0272432
665.0000</									

TABLE 3—Continued

TEMPERATURE		26.60							
550.0000	.0222399	551.0000	.0222824	552.0000	.0223248	553.0000	.0223673	554.0000	.0224098
555.0000	.0224522	556.0000	.0224947	557.0000	.0225371	558.0000	.0225796	559.0000	.0226221
560.0000	.0226645	561.0000	.0227070	562.0000	.0227494	563.0000	.0227919	564.0000	.0228344
565.0000	.0228768	566.0000	.0229193	567.0000	.0229617	568.0000	.0230042	569.0000	.0230467
570.0000	.0230891	571.0000	.0231316	572.0000	.0231741	573.0000	.0232165	574.0000	.0232590
575.0000	.0233014	576.0000	.0233439	577.0000	.0233864	578.0000	.0234288	579.0000	.0234713
580.0000	.0235137	581.0000	.0235562	582.0000	.0235987	583.0000	.0236411	584.0000	.0236836
585.0000	.0237260	586.0000	.0237685	587.0000	.0238110	588.0000	.0238534	589.0000	.0238959
590.0000	.0239384	591.0000	.0239808	592.0000	.0240233	593.0000	.0240657	594.0000	.0241082
595.0000	.0241507	596.0000	.0241931	597.0000	.0242356	598.0000	.0242780	599.0000	.0243205
600.0000	.0243630	601.0000	.0244054	602.0000	.0244479	603.0000	.0244904	604.0000	.0245328
605.0000	.0245753	606.0000	.0246177	607.0000	.0246602	608.0000	.0247027	609.0000	.0247451
610.0000	.0247876	611.0000	.0248300	612.0000	.0248725	613.0000	.0249150	614.0000	.0249574
615.0000	.0249999	616.0000	.0250423	617.0000	.0250848	618.0000	.0251273	619.0000	.0251697
620.0000	.0252122	621.0000	.0252547	622.0000	.0252971	623.0000	.0253396	624.0000	.0253820
625.0000	.0254245	626.0000	.0254670	627.0000	.0255094	628.0000	.0255519	629.0000	.0255943
630.0000	.0256368	631.0000	.0256793	632.0000	.0257217	633.0000	.0257642	634.0000	.0258067
635.0000	.0258491	636.0000	.0258916	637.0000	.0259340	638.0000	.0259765	639.0000	.0260190
640.0000	.0260614	641.0000	.0261039	642.0000	.0261463	643.0000	.0261888	644.0000	.0262313
645.0000	.0262737	646.0000	.0263162	647.0000	.0263586	648.0000	.0264011	649.0000	.0264436
650.0000	.0264860	651.0000	.0265285	652.0000	.0265710	653.0000	.0266134	654.0000	.0266559
655.0000	.0266983	656.0000	.0267408	657.0000	.0267833	658.0000	.0268257	659.0000	.0268682
660.0000	.0269106	661.0000	.0269531	662.0000	.0269956	663.0000	.0270380	664.0000	.0270805
665.0000	.0271229	666.0000	.0271654	667.0000	.0272079	668.0000	.0272503	669.0000	.0272928
670.0000	.0273353	671.0000	.0273777	672.0000	.0274202	673.0000	.0274626	674.0000	.0275051
675.0000	.0275476	676.0000	.0275900	677.0000	.0276325	678.0000	.0276749	679.0000	.0277174
680.0000	.0277599	681.0000	.0278023	682.0000	.0278448	683.0000	.0278873	684.0000	.0279297
685.0000	.0279722	686.0000	.0280146	687.0000	.0280571	688.0000	.0280996	689.0000	.0281420
690.0000	.0281845	691.0000	.0282269	692.0000	.0282694	693.0000	.0283119	694.0000	.0283543
695.0000	.0283968	696.0000	.0284392	697.0000	.0284817	698.0000	.0285242	699.0000	.0285666
700.0000	.0286091	701.0000	.0286516	702.0000	.0286940	703.0000	.0287365	704.0000	.0287789
705.0000	.0288214	706.0000	.0288639	707.0000	.0289063	708.0000	.0289488	709.0000	.0289912
710.0000	.0290337	711.0000	.0290762	712.0000	.0291186	713.0000	.0291611	714.0000	.0292035
715.0000	.0292460	716.0000	.0292885	717.0000	.0293309	718.0000	.0293734	719.0000	.0294159
720.0000	.0294583	721.0000	.0295008	722.0000	.0295432	723.0000	.0295857	724.0000	.0296282
725.0000	.0296706	726.0000	.0297131	727.0000	.0297555	728.0000	.0297980	729.0000	.0298405
730.0000	.0298829	731.0000	.0299254	732.0000	.0299679	733.0000	.0300103	734.0000	.0300528
735.0000	.0300952	736.0000	.0301377	737.0000	.0301802	738.0000	.0302226	739.0000	.0302651
740.0000	.0303075	741.0000	.0303500	742.0000	.0303925	743.0000	.0304349	744.0000	.0304774
745.0000	.0305198	746.0000	.0305623	747.0000	.0306048	748.0000	.0306472	749.0000	.0306897
750.0000	.0307322	751.0000	.0307746	752.0000	.0308171	753.0000	.0308595	754.0000	.0309020
755.0000	.0309445	756.0000	.0309869	757.0000	.0310294	758.0000	.0310718	759.0000	.0311143
760.0000	.0311568	761.0000	.0311992	762.0000	.0312417	763.0000	.0312842	764.0000	.0313266
765.0000	.0313691	766.0000	.0314115	767.0000	.0314540	768.0000	.0314965	769.0000	.0315389
770.0000	.0315814	771.0000	.0316238	772.0000	.0316663	773.0000	.0317088	774.0000	.0317512
775.0000	.0317937	776.0000	.0318361	777.0000	.0318786	778.0000	.0319211	779.0000	.0319635
780.0000	.0320060	781.0000	.0320485	782.0000	.0320909	783.0000	.0321334	784.0000	.0321758
785.0000	.0322183	786.0000	.0322608	787.0000	.0323032	788.0000	.0323457	789.0000	.0323881
790.0000	.0324306	791.0000	.0324731	792.0000	.0325155	793.0000	.0325580	794.0000	.0326004
795.0000	.0326429	796.0000	.0326854	797.0000	.0327278	798.0000	.0327703	799.0000	.0328128

TEMPERATURE		26.80							
550.0000	.0221035	551.0000	.0221457	552.0000	.0221880	553.0000	.0222302	554.0000	.0222724
555.0000	.0223146	556.0000	.0223569	557.0000	.0223991	558.0000	.0224413	559.0000	.0224835
560.0000	.0225258	561.0000	.0225680	562.0000	.0226102	563.0000	.0226524	564.0000	.0226947
565.0000	.0227369	566.0000	.0227791	567.0000	.0228213	568.0000	.0228636	569.0000	.0229058
570.0000	.0229480	571.0000	.0229903	572.0000	.0230325	573.0000	.0230747	574.0000	.0231169
575.0000	.0231592	576.0000	.0232014	577.0000	.0232436	578.0000	.0232858	579.0000	.0233281
580.0000	.0233703	581.0000	.0234125	582.0000	.0234547	583.0000	.0234970	584.0000	.0235392
585.0000	.0235814	586.0000	.0236236	587.0000	.0236659	588.0000	.0237081	589.0000	.0237503
590.0000	.0237925	591.0000	.0238348	592.0000	.0238770	593.0000	.0239192	594.0000	.0239614
595.0000	.0240037	596.0000	.0240459	597.0000	.0240881	598.0000	.0241304	599.0000	.0241726
600.0000	.0242148	601.0000	.0242570	602.0000	.0242993	603.0000	.0243415	604.0000	.0243837
605.0000	.0244259	606.0000	.0244682	607.0000	.0245104	608.0000	.0245526	609.0000	.0245948
610.0000	.0246371	611.0000	.0246793	612.0000	.0247215	613.0000	.0247637	614.0000	.0248060
615.0000	.0248482	616.0000	.0248904	617.0000	.0249326	618.0000	.0249749	619.0000	.0250171
620.0000	.0250593	621.0000	.0251015	622.0000	.0251438	623.0000	.0251860	624.0000	.0252282
625.0000	.0252705	626.0000	.0253127	627.0000	.0253549	628.0000	.0253971	629.0000	.0254394
630.0000	.0254816	631.0000	.0255238	632.0000	.0255660	633.0000	.0256083	634.0000	.0256505
635.0000	.0256927	636.0000	.0257349	637.0000	.0257772	638.0000	.0258194	639.0000	.0258616
640.0000	.0259038	641.0000	.0259461	642.0000	.0259883	643.0000	.0260305	644.0000	.0260727
645.0000	.0261150	646.0000	.0261572	647.0000	.0261994	648.0000	.0262416	649.0000	.0262839
650.0000	.0263261	651.0000	.0263683	652.0000	.0264106	653.0000	.0264528	654.0000	.0264950
655.0000	.0265372	656.0000	.0265795	657.0000	.0266217	658.0000	.0266639	659.0000	.0267061
660.0000	.0267484	661.0000	.0267906	662.0000	.0268328	663.0000	.0268750	664.0000	.0269173
665.0000	.0269595								

TABLE 4

F factors. These values are calculated from the expression $F = \Delta V/V \times 1000$. These dilution factors are given in 0.1 ml increments for 100, 200, or 300 ml samples up to an F value of 99.0991. F factors are to be multiplied by M or M-X for each increment of titrant added, depending on whether the abbreviated or more accurate equation is to be used.

F factors increment of titrant	100	Volume 200	300	F factors increment of titrant	100	Volume 200	300
.1	.9990	.4998	.3332	6.3	59.2662	30.5381	20.5681
.2	1.9960	.9990	.6662	6.4	60.1504	31.0078	20.8877
.3	2.9910	1.4978	.9990	6.5	61.0329	31.4770	21.2072
.4	3.9841	1.9960	1.3316	6.6	61.9137	31.9458	21.5264
.5	4.9751	2.4938	1.6639	6.7	62.7929	32.4141	21.8455
.6	5.9642	2.9910	1.9960	6.8	63.6704	32.8820	22.1643
.7	6.9513	3.4878	2.3279	6.9	64.5463	33.3494	22.4829
.8	7.9365	3.9841	2.6596	7.0	65.4206	33.8164	22.8013
.9	8.9197	4.4798	2.9910	7.1	66.2932	34.2830	23.1195
1.0	9.9010	4.9751	3.3223	7.2	67.1642	34.7490	23.4375
1.1	10.8803	5.4699	3.6533	7.3	68.0336	35.2147	23.7553
1.2	11.8577	5.9642	3.9841	7.4	68.9013	35.6798	24.0729
1.3	12.8332	6.4580	4.3146	7.5	69.7674	36.1446	24.3902
1.4	13.8067	6.9513	4.6450	7.6	70.6320	36.6089	24.7074
1.5	14.7783	7.4442	4.9751	7.7	71.4949	37.0727	25.0244
1.6	15.7480	7.9365	5.3050	7.8	72.3562	37.5361	25.3411
1.7	16.7158	8.4284	5.6347	7.9	73.2159	37.9990	25.6577
1.8	17.6817	8.9197	5.9642	8.0	74.0741	38.4615	25.9740
1.9	18.6457	9.4106	6.2935	8.1	74.9306	38.9236	26.2902
2.0	19.6078	9.9010	6.6225	8.2	75.7856	39.3852	26.6061
2.1	20.5681	10.3909	6.9513	8.3	76.6390	39.8464	26.9218
2.2	21.5264	10.8803	7.2799	8.4	77.4908	40.3071	27.2374
2.3	22.4829	11.3693	7.6083	8.5	78.3410	40.7674	27.5527
2.4	23.4375	11.8577	7.9365	8.6	79.1897	41.2272	27.8678
2.5	24.3902	12.3457	8.2645	8.7	80.0368	41.6866	28.1827
2.6	25.3411	12.8332	8.5922	8.8	80.8824	42.1456	28.4974
2.7	26.2902	13.3202	8.9197	8.9	81.7264	42.6041	28.8119
2.8	27.2374	13.8067	9.2470	9.0	82.5688	43.0622	29.1262
2.9	28.1827	14.2928	9.5741	9.1	83.4097	43.5198	29.4403
3.0	29.1262	14.7783	9.9010	9.2	84.2491	43.9771	29.7542
3.1	30.0679	15.2634	10.2276	9.3	85.0869	44.4338	30.0679
3.2	31.0078	15.7480	10.5541	9.4	85.9232	44.8902	30.3814
3.3	31.9458	16.2322	10.8803	9.5	86.7580	45.3461	30.6947
3.4	32.8820	16.7158	11.2063	9.6	87.5912	45.8015	31.0078
3.5	33.8164	17.1990	11.5321	9.7	88.4230	46.2566	31.3206
3.6	34.7490	17.6817	11.8577	9.8	89.2532	46.7112	31.6333
3.7	35.6798	18.1640	12.1831	9.9	90.0819	47.1653	31.9458
3.8	36.6089	18.6457	12.5082	10.0	90.9091	47.6190	32.2581
3.9	37.5361	19.1270	12.8332	10.1	91.7348	48.0723	32.5701
4.0	38.4615	19.6078	13.1579	10.2	92.5590	48.5252	32.8820
4.1	39.3852	20.0882	13.4824	10.3	93.3817	48.9777	33.1937
4.2	40.3071	20.5681	13.8067	10.4	94.2029	49.4297	33.5052
4.3	41.2272	21.0475	14.1308	10.5	95.0226	49.8812	33.8164
4.4	42.1456	21.5264	14.4547	10.6	95.8409	50.3324	34.1275
4.5	43.0622	22.0049	14.7783	10.7	96.6576	50.7831	34.4384
4.6	43.9771	22.4829	15.1018	10.8	97.4729	51.2334	34.7490
4.7	44.8902	22.9604	15.4250	10.9	98.2867	51.6833	35.0595
4.8	45.8015	23.4375	15.7480	11.0	99.0991	52.1327	35.3698
4.9	46.7112	23.9141	16.0708	11.1		52.5817	35.6798
5.0	47.6190	24.3902	16.3934	11.2		53.0303	35.9897
5.1	48.5252	24.8659	16.7158	11.3		53.4785	36.2994
5.2	49.4297	25.3411	17.0380	11.4		53.9262	36.6089
5.3	50.3324	25.8159	17.3600	11.5		54.3735	36.9181
5.4	51.2334	26.2902	17.6817	11.6		54.8204	37.2272
5.5	52.1327	26.7640	18.0033	11.7		55.2669	37.5361
5.6	53.0303	27.2374	18.3246	11.8		55.7129	37.8448
5.7	53.9262	27.7103	18.6457	11.9		56.1586	38.1533
5.8	54.8204	28.1827	18.9666	12.0		56.6038	38.4615
5.9	55.7129	28.6547	19.2873	12.1		57.0486	38.7696
6.0	56.6038	29.1262	19.6078	12.2		57.4929	39.0775
6.1	57.4929	29.5973	19.9281	12.3		57.9369	39.3852
6.2	58.3804	30.0679	20.2482	12.4		58.3804	39.6927

TABLE 4—Continued

F factors increment of tritrant	Volume 200	300	F factors increment of tritrant	Volume 200	300
12.5	58.8235	40.0000	19.1	87.1748	59.8558
12.6	59.2662	40.3071	19.2	87.5912	60.1504
12.7	59.7085	40.6140	19.3	88.0073	60.4447
12.8	60.1504	40.9207	19.4	88.4230	60.7389
12.9	60.5918	41.2272	19.5	88.8383	61.0329
13.0	61.0329	41.5335	19.6	89.2532	61.3267
13.1	61.4735	41.8397	19.7	89.6677	61.6203
13.2	61.9137	42.1456	19.8	90.0819	61.9137
13.3	62.3535	42.4513	19.9	90.4957	62.2069
13.4	62.7929	42.7569	20.0	90.9091	62.5000
13.5	63.2319	43.0622	20.1	91.3221	62.7929
13.6	63.6704	43.3673	20.2	91.7348	63.0856
13.7	64.1086	43.6723	20.3	92.1471	63.3781
13.8	64.5463	43.9771	20.4	92.5590	63.6704
13.9	64.9836	44.2816	20.5	92.9705	63.9626
14.0	65.4206	44.5860	20.6	93.3817	64.2545
14.1	65.8571	44.8902	20.7	93.7925	64.5463
14.2	66.2932	45.1941	20.8	94.2029	64.8379
14.3	66.7289	45.4979	20.9	94.6129	65.1293
14.4	67.1642	45.8015	21.0	95.0226	65.4206
14.5	67.5991	46.1049	21.1	95.4319	65.7116
14.6	68.0336	46.4081	21.2	95.8409	66.0025
14.7	68.4676	46.7112	21.3	96.2494	66.2932
14.8	68.9013	47.0140	21.4	96.6576	66.5837
14.9	69.3346	47.3166	21.5	97.0655	66.8740
15.0	69.7674	47.6190	21.6	97.4729	67.1642
15.1	70.1999	47.9213	21.7	97.8800	67.4541
15.2	70.6320	48.2234	21.8	98.2867	67.7439
15.3	71.0636	48.5252	21.9	98.6931	68.0336
15.4	71.4949	48.8269	22.0	99.0991	68.3230
15.5	71.9258	49.1284	22.1		68.6122
15.6	72.3562	49.4297	22.2		68.9013
15.7	72.7863	49.7308	22.3		69.1902
15.8	73.2159	50.0317	22.4		69.4789
15.9	73.6452	50.3324	22.5		69.7674
16.0	74.0741	50.6329	22.6		70.0558
16.1	74.5025	50.9332	22.7		70.3440
16.2	74.9306	51.2334	22.8		70.6320
16.3	75.3583	51.5334	22.9		70.9198
16.4	75.7856	51.8331	23.0		71.2074
16.5	76.2125	52.1327	23.1		71.4949
16.6	76.6390	52.4321	23.2		71.7822
16.7	77.0651	52.7313	23.3		72.0693
16.8	77.4908	53.0303	23.4		72.3562
16.9	77.9161	53.3291	23.5		72.6430
17.0	78.3410	53.6278	23.6		72.9295
17.1	78.7655	53.9262	23.7		73.2159
17.2	79.1897	54.2245	23.8		73.5022
17.3	79.6134	54.5225	23.9		73.7882
17.4	80.0368	54.8204	24.0		74.0741
17.5	80.4598	55.1181	24.1		74.3598
17.6	80.8824	55.4156	24.2		74.6453
17.7	81.3045	55.7129	24.3		74.9306
17.8	81.7264	56.0101	24.4		75.2158
17.9	82.1478	56.3070	24.5		75.5008
18.0	82.5688	56.6038	24.6		75.7856
18.1	82.9895	56.9003	24.7		76.0702
18.2	83.4097	57.1967	24.8		76.3547
18.3	83.8296	57.4929	24.9		76.6390
18.4	84.2491	57.7889	25.0		76.9231
18.5	84.6682	58.0848	25.1		77.2070
18.6	85.0869	58.3804	25.2		77.4908
18.7	85.5053	58.6759	25.3		77.7744
18.8	85.9232	58.9711	25.4		78.0578
18.9	86.3408	59.2662	25.5		78.3410
19.0	86.7580	59.5611	25.6		78.6241

TABLE 4—Continued

F factors increment of tritrant	Volume	300	F factors increment of tritrant	Volume	300
25.7		78.9070	29.4		89.2532
25.8		79.1897	29.5		89.5296
25.9		79.4722	29.6		89.8058
26.0		79.7546	29.7		90.0819
26.1		80.0368	29.8		90.3578
26.2		80.3188	29.9		90.6335
26.3		80.6007	30.0		90.9091
26.4		80.8824	30.1		91.1845
26.5		81.1639	30.2		91.4597
26.6		81.4452	30.3		91.7348
26.7		81.7264	30.4		92.0097
26.8		82.0073	30.5		92.2844
26.9		82.2882	30.6		92.5590
27.0		82.5688	30.7		92.8334
27.1		82.8493	30.8		93.1076
27.2		83.1296	30.9		93.3817
27.3		83.4097	31.0		93.6556
27.4		83.6897	31.1		93.9293
27.5		83.9695	31.2		94.2029
27.6		84.2491	31.3		94.4763
27.7		84.5285	31.4		94.7495
27.8		84.8078	31.5		95.0226
27.9		85.0869	31.6		95.2955
28.0		85.3659	31.7		95.5683
28.1		85.6446	31.8		95.8409
28.2		85.9232	31.9		96.1133
28.3		86.2016	32.0		96.3855
28.4		86.4799	32.1		96.6576
28.5		86.7580	32.2		96.9296
28.6		87.0359	32.3		97.2013
28.7		87.3137	32.4		97.4729
28.8		87.5912	32.5		97.7444
28.9		87.8687	32.6		98.0156
29.0		88.1459	32.7		98.2867
29.1		88.4230	32.8		98.5577
29.2		88.6999	32.9		98.8285
29.3		88.9766	33.0		99.0991

TABLE 5

Format for placing the millimole pH data on data cards. There must be exact correspondence in location on cards between the pH values in this table and the corresponding carbon dioxide values (table PHC) from the titration graph.

14.0	13.9	13.8	13.7	13.6	13.5	13.4	13.3	13.2	13.1	13.0	12.9	12.8	12.7
12.6	12.5	12.4	12.3	12.2	12.1	12.0	11.9	11.8	11.7	11.6	11.5	11.4	11.3
11.2	11.1	11.0	10.9	10.8	10.7	10.6	10.5	10.4	10.3	10.2	10.1	10.0	9.9
9.8	9.7	9.6	9.5	9.4	9.3	9.2	9.1	9.0	8.9	8.8	8.7	8.6	8.5
8.4	8.3	8.2	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.4	7.3	7.2	7.1
7.0	6.9	6.8	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.7

ture values are the same. This situation is usual where the barometer and tonometer are in the same room.

If X is the initial carbon dioxide concentration in millimoles per ml in the sample, the total amount of carbon dioxide in the beaker in millimoles after each step of the titration may be indicated by the expression:

$$\text{Total CO}_2 = (V_0 X + \Delta V M) \quad (2)$$

where

V_0 is the initial volume in the beaker (100, 200, or 300 ml)

ΔV is the total volume of titrant added up to that step in the titration in ml.

M is the quantity derived in equation (1) (mM CO_2 /ml titrant).

The final volume of fluid in the beaker at the end of any given step (V) is expressed by the relationship:

$$V = V_0 + \Delta V \quad (3)$$

Dividing each side of equation (2) by V , an expression for the concentration of total carbon dioxide $[\text{CO}_{2T}]$ in mM/ml may be obtained:

$$[\text{CO}_{2T}] = \frac{V_0 X + \Delta V M}{V} \quad (4)$$

The change in concentration of CO_2 ($\Delta[\text{CO}_{2T}]$) from the beginning of the titration to the end of any given step is given by the equation:

$$\Delta[\text{CO}_{2T}] = [\text{CO}_{2T}] - X \quad (5)$$

Substituting equation (4) in equation (5) the expression becomes:

$$\Delta[\text{CO}_{2T}] = \frac{V_0 X + \Delta V M}{V} - X \quad (6)$$

Rearranging and factoring out, the expression becomes:

$$\Delta[\text{CO}_{2T}] = X \frac{(V_0 - V) + \Delta V M}{V} \quad (7)$$

Substituting $-\Delta V$ for $V_0 - V$ (from equation 3) the expression becomes:

$$\Delta[\text{CO}_{2T}] = X \frac{(-\Delta V) + \Delta V M}{V} \quad (8)$$

Factoring out ΔV the expression becomes:

$$\Delta[\text{CO}_{2T}] = \frac{\Delta V}{V} (M - X) \quad (9)$$

The term F may be used to represent the dilution factor $\Delta V/V$. Substituting F in equation 10 we derive the final expression:

$$\Delta[\text{CO}_{2T}] = F (M - X) \quad (10)$$

Since X is small after sweeping the sample with a carbon dioxide-free gas, and since the whole titration involves a small volume change, FX is small and may be ignored. The "F" factors (times 1000 to correct to a liter basis) for the usual titration increments and sample volumes used are included as Table 4. Where FX is small:

$$\Delta[\text{CO}_{2T}] = F M \quad (11)$$

Raw data from a typical titration of sea water are shown in Table 2. When this titration was done, the observed barometric pressure was 765.2 mm Hg on a standard mercurial barometer with a brass scale. The temperature of the barometer and titrant was 24.4°C . Entering the M value table with 24.4°C and a barometric pressure of 765, (the uncorrected barometric pressure to the nearest mmHg) we find an M value of 0.03347. This is the concentration of carbon dioxide in millimoles dissolved in one ml of distilled water under the true barometric pressure (partial pressure of the gas plus the aqueous tension at the stated temperature) and the observed temperature of the titrant.

What is now desired is a curve showing the relationship between the pH of the sample and the amount of carbon dioxide dissolved in the sample. Data as to the volumes of titrant added from Column 2, Table 2 were used with Table 4 to obtain the F factors. The F factors were multiplied by the M value (Table 3) to obtain a relative value for carbon dioxide concentration at each pH. These data are shown in Column 3, Table 2 and Fig. 2. This method of calculation follows expression (11). For studies with better than

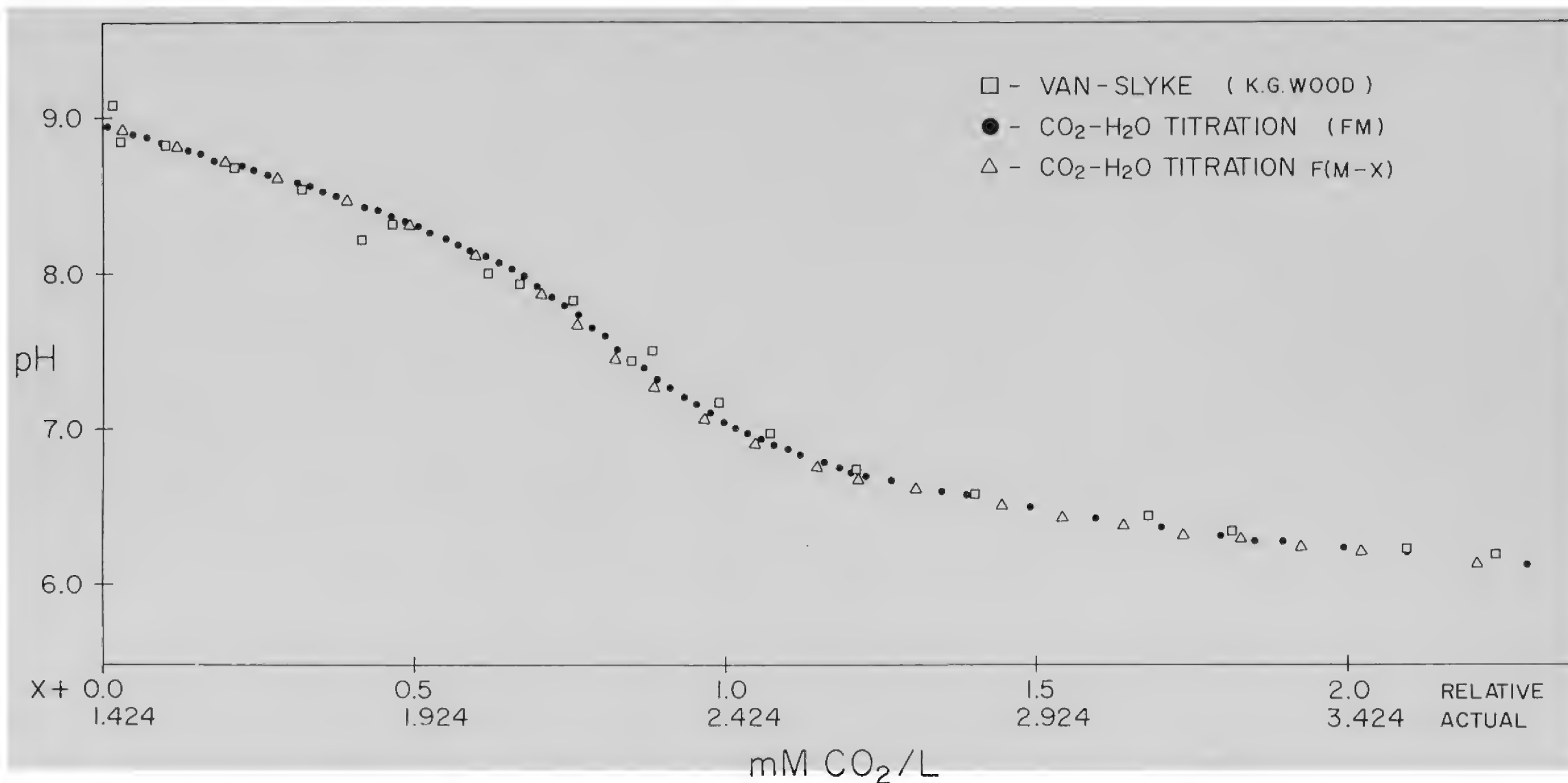


FIG. 2. Typical graph produced by carbon dioxide-water titration of sea water (salinity 31.8‰). The quantity X represents the concentration of carbon dioxide in the sea water at the start of the titration. Van Slyke determinations of carbon dioxide concentration at several pH's on a duplicate sample are plotted for comparison (Wood, 1963). Total carbon dioxide concentration by equation (10) and relative carbon dioxide concentration by equation (11), the abbreviated method, are plotted with separate scales on the abscissa.

5% accuracy, the initial carbon dioxide content (X) need not be determined. Where it is required, X may be determined with the Van Slyke method or with the infrared analyzer procedure of Wilson (1961). X may be approximated by the total alkalinity in high pH water if carbonate and bicarbonate are the only factors affecting the buffer system. Also given in Table 2 (Column 4) and plotted in Fig. 2 are the actual concentrations of carbon dioxide in the sea water based on the more accurate expression (10) and Dr. K. G. Wood's determination of X (0.001424 mM/ml at pH 8.93).

The slope of the titration curve is directly influenced by the buffering capacity of the water. If a very hard water is used, the slope of the titration curve will be shallow, and if a very soft water is used, the slope will be much steeper. The same relationship holds true for the amount of time required to raise the pH of the water prior to titration. The harder the water, the greater the length of treatment with nitrogen or carbon dioxide free air necessary to raise the sample to a given pH.

Diurnal Graph Computer Program

pH-carbon dioxide graphs such as shown in Fig. 2 may be used with observed changes in pH taken from recorder charts to compute changes in carbon associated with metabolism and other processes of carbon dioxide exchange (Beyers, 1963a). Where data are extensive, it may be convenient to make calculations with a computer program. Such a computer program for the Control Data Corporation 1604 Digital Computer was developed to perform rapid calculation of respiration and production values from pH data by the methods presented earlier. Using hourly pH data, the machine interpolates from a pH-CO₂ titration graph the amount of CO₂ corresponding to that pH. The pH-CO₂ graph is made available for this computation by taking millimoles of CO₂ values for every 0.1 pH unit from the titration graph (covering the range of the diurnal pH's), placing them according to a prescribed format on data cards corresponding to the pH values given in Table 5, and feeding them, with a data identification number, pH data, light condition change times, a light sequence code number, and depth into the machine. With this information the program will compute the carbon dioxide values for each pH value, the increment of change between it and the next value, and, by integrating, calculate production and respiration values and their ratio. Further detail on format of data, order of data, etc, will be given below. The program description and a source deck of cards may be obtained by writing to the University of Texas Computation Center Program Library, Austin, Texas. M2 UTEX PRBYPH is the program name and should be given if a program request is made.

A program print-out is given below, and references to format statement numbers will be made as the data list is described. Input data format is as follows:

READ 99, NTRA

99 FORMAT (I4)

NTRA—an integer, the number of sets of pH-CO₂ titration graph values to be read in. This number is right-adjusted in its field (Columns 1-4).

READ 130, PHC

130 FORMAT (14F5.3)

PHC—a table of 84 values of carbon dioxide taken from a pH-CO₂ titration graph which correspond to the pH values of Table 5.

READ 99, NTRB

99 FORMAT (I4)

NTRB—an integer, the number of sets of pH data to be read in for each PHC table.

This number is right-adjusted in its field (Columns 1–4).

READ 110, NAME

110 FORMAT (I10)

NAME—an integer number whereby the user must identify each set of pH data. This number may contain up to 10 digits and occupies Columns 1–10.

READ 100, PH

100 FORMAT (14F5.2)

PH—a set of 25 pH values corresponding to pH readings taken every hour for a period of 24 hours.

READ 140, KTIME, KCODE, DEPTH

140 FORMAT (3I5, F6.3)

KTIME—two integer numbers which designate the times at which changes in light conditions occur (on to off or off to on). There are usually two such changes, and the numbers are derived by listing the pH data in a numbered Column (1, 2, 3, . . . , 25). The number of the pH value at which the first change occurs is the first KTIME value and is right-adjusted in Columns 1–5. The number of the pH value at which the second change occurs is the second KTIME value and is right-adjusted in Columns 6–10. If only one light condition change occurs, the first KTIME value is 1, and the second number of the pH value at which the change occurs.

KCODE—a control parameter, either 1 or 2 as determined by the sequence of light changes. The following table indicates which number is appropriate:

Code	Light condition sequence
1	off—on on—off—on
2	on—off off—on—off

This number is placed in Column 15.

DEPTH—a decimal number giving, in meters and to an increment limit of 1 millimeter, the depth of the experimental location. This number is placed in Columns 16–21.

The data are punched on cards in the order listed then placed with the source deck as prescribed by the particular monitor program on the computer used. Table 5 is generated by the program and is used in interpolation.

Two cautions should be made to the user. First, the program should be checked to insure compatibility between it and the computer on which it is run. Second, in the table PHC all 84 values must be represented whether by carbon dioxide values or by blank spaces.

A computer program (M2 UTEX CARBON) which performs the same tasks as this one and plots the pH and rate of change values is available.

Computation time per set of data is approximately 7 seconds as compared to less than one second per set of data with the above program.

PROGRAM PRBYPH

CALL LIMIT (20)

C CONVERSION OF PH TO CARBON

```

    0DIMENSION PHT(84),PHC(84),PH(25),KTIME(2),C12(25),DER(24)
    99 FORMAT(I4)
    100 FORMAT(14F5.2)
    110 FORMAT(I10)
    111 FORMAT(15H IDENTIFICATION 4X,I10)
    120 FORMAT(15H PROGRAM PRBYPH / 21H BY NEAL E. ARMSTRONG)
    130 FORMAT(14F5.3)
    200 FORMAT(1H1)
        PRINT 200
        PRINT 120
        PRINT 200
        PHT(1)=14.0
        DO 170 I=1,83
170  PHT(I+1)=14.0-(0.1*FLOATF(I))
        READ 99,NTRA
        NCNB=0
129  READ 130,PHC
        READ 99,NTRB
        NCNT=0
131  READ 110,NAME
        READ 100,PH
        RSV(PHI=1).
        DO 201 I=1,25
            PHI=PH(I)
            RSV(W1=1,W2=1,W3=1).
            LDA(PHI),ENI2(84),+THS2(PHT),SLJ(201),LDA2(PHT),STA(W1),
            LDA2(PHC),STA(W2),SIU2(106),
106  ENI2(N),INI2(1),
            LDA2(PHC),STA(W3).
            PHI=10.0*((W3-W2)*(W1-PH(I)))
            C12(I)=W2+PHI
201  CONTINUE
        DO 202 I=1,24
            DER(I)=C12(I+1)-C12(I)
202  CONTINUE
        PRINT 111,NAME
132  FORMAT(/3H PH 10X 7H CARBON 5X 17H CHANGE INCREMENT /)
        PRINT 132
133  FORMAT(1X,F6.3,9X,F6.3,6X,F6.3)
        PRINT 133,(PH(I),C12(I),DER(I),I=1,24)
        PRINT 133,PH(25),C12(25)
140  FORMAT(3I5,F6.3)
        READ 140,KTIME,KCODE,DEPTH
        K=1
        AONE=0.0
        IF(KTIME(1)-1)141,146,141

```

```
141 MM=2
    KTM=KTIME(1)-1
138 ACA=DER(MM-1)
148 DO 142 I=MM,KTM
    ACA=ACA+DER(I)
142 CONTINUE
    GO TO (143,144,145),K
143 AONE=ACA
144 ATWO=ACA
145 ATHR=ACA+AONE
146 IF(K-2) 147,149,150
147 K=K+1
    MM=KTIME(1)+1
    KTM=KTIME(2)-1
    GO TO 138
149 K=K+1
    MM=KTIME(2)+1
    KTM=24
    GO TO 138
150 ABA=ABSF((ATWO*DEPTH)*44.0)
    ABB=ABSF((ATHR*DEPTH)*44.0)
    IF(KTIME(1)-1) 151,152,151
151 KHB=KTIME(1)+(24-KTIME(2))
    KHA=KTIME(2)-KTIME(1)
    GO TO 160
152 KHA=KTIME(2)-1
    KHB=24-KTIME(2)+1
1600FORMAT(/11H PRODUCTION /1X,F6.3,2X,10H MM CO2/L/ 12,4H HRS
    1/1X,F6.3,2X,12H GMS CO2/M2/ 12,4H HRS)
1610FORMAT(/12H RESPIRATION /1X,F6.3,2X,10H MM CO2/L/12,4H HRS
    1/1X,F6.3,2X,12H GMS CO2/M2/12,4H HRS)
    GO TO (162,163),KCODE
162 KA=KHB
    ATHR=ABSF(ATHR)
    PRINT 160,ATHR,KA,ABB,KA
    KB=KHA
    PRINT 161,ATWO,KB,ABA,KB
    RATIO=ABB/ABA
    GO TO 164
163 KA=KHA
    ATWO=ABSF(ATWO)
    PRINT 160,ATWO,KA,ABA,KA
    KB=KHB
    PRINT 161,ATHR,KB,ABB,KB
    RATIO=ABA/ABB
164 CONTINUE
```

```

165 FORMAT(/10H P/R RATIO, 2X,F6.3)
    PRINT 165,RATIO
121 FORMAT (13H TIME CHANGES 2X,216/5H CODE 2X,14/6H DEPTH
    2X,F6.3)
    PRINT 121,KTIME,KCODE,DEPTH
    PRINT 200
    NCNT=NCNT+1
    IF (NCNT-NTRB) 131,167,167
167 NCNB=NCNB+1
    IF (NCNB-NTRA) 129,166,166
166 CONTINUE
    END
    END

```

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